PROJECT PLAN 207 INTEGRATED FARMING SYSTEMS

Agricultural Systems Research Unit
Northern Plains Agricultural Research Laboratory
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Ecologically-Sound Pest, Water and Soil Management Strategies for Northern Great Plains Cropping Systems

NP 207 (70%) & NP 201 (30%)

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PROJECT SUMMARY

A detailed research program has been formulated to address pressing dryland and irrigated agricultural production issues in the Northern Great Plains. It focuses on increased farming efficiency, reduced reliance on agrochemicals and increased overall farm profitability. Research centers on evaluating holistic management strategies and practices called **integrated crop production systems** (ICPS) that consider efficient use of precipitation and irrigation waters, soil and water quality, reduced tillage, ecologically-based cultural operations, management and economically viable crop rotations. Management strategies are directed towards minimizing use of pesticides, maintaining high yield quality and quantity, and improving soil quality using environmentally sensitive methods and procedures. Selected natural antagonists (i.e., fungi), plant protection mechanisms and cultural practices will be evaluated for use in dynamic bio-based disease and weed suppression strategies.

The primary research issues under **Objective 1** deal with the improvement of irrigated and dryland cropping systems through developing better understandings of the advantages and limitations of existing and proposed farming systems, and to develop biological approaches that can improve production efficiency and reduce grower input costs. The focus of **Objective 2** is specifically on evaluating outcomes and quantifying environmental benefits and/or drawbacks that may result from the biologically-based farming strategies and practices developed in the first objective. Carryover effects of different rotations are important and need to be closely followed in the different tillage and management treatments. **Objective 3** focuses on extending the research and the use of existing management models from subfield scale project findings to the whole field, local and regional level.

Keywords: crop production, dryland, irrigation, soil quality, water quality, weeds, plant disease, ecology, biocontrol, integrated cropping systems, integrated pest management.

Objectives

1. To develop diverse irrigated and dryland cropping strategies and technologies (e.g., variations in fertilizer application methods, row spacing, cultivar selection, seeding rates, planting timing, strip tillage, zero tillage) that increase farm profitability, productivity and soil and water quality while maximizing agrochemical, water and nutrient use efficiencies. *[Management issues]*
2. To quantify environmental benefits from improved soil and water management, diverse crop rotations, reduced tillage, and selected combinations of cultural practices on plant, soil and water resources (e.g., reduced fertilizers and pesticides in leachate and field run off; improved soil water storage and use; reduced incidence of diseases and weeds; optimized nutrient cycling; and, increased soil biodiversity under the cropping systems developed above [see Obj 1] for irrigated and dryland agriculture.) *[Public safety, environmental and ecology issues]*
3. To extend research results and increase adoption rates by testing promising plot research outcomes on growers' fields, and by using feedback from both plot and field research scales to calibrate existing models (e.g., GPFARM, CPED) for uses in combination with GIS and other valid management tools (e.g., meteorological networks, remote sensing, electrical conductivity (EC) mapping, and yield maps.) *[Technology transfer]*

Need for Research

The Agricultural Systems Research Unit (ASRU) at the Northern Plains Agricultural Research Laboratory (NPARL) near Sidney, Montana (http://www.sidney.ars.usda.gov/) is uniquely positioned to provide innovative and credible solutions to many regional agricultural and natural resource problems. It is located at the confluence of the Missouri and Yellowstone Rivers, which have abundant, high quality water and land resources for substantial irrigation development. In the large dryland production areas, high rates of soil erosion and a decrease in soil organic matter (OM), by at least 50% in the last century, indicate that traditional farming practices in the region are ecologically unsustainable. Furthermore, about 28% of total farm income in eastern Montana and western North Dakota (the "MonDak" region) is derived from Federal transfer payments, confirming that current farming systems are economically unsustainable under current world markets. The integration of diverse cropping systems and cultural practices with improved water, pest, and nutrient management practices and technologies that protect the environment and improve the economic benefits of irrigated and dryland agriculture are key to the success of future farming enterprises in the region.

A major agronomic concern is the limited diversity of crops in the region. The strong dependence on wheat-fallow production systems common to the north central portion of the US is compounded by economic and ecological problems including water quality, endangered species, rising energy costs, competing downstream water uses, excessive soil loss and reduced nutrient cycling rates that are impaired by past management practices. Furthermore, the semi-arid climate (300-360 mm/yr), results in frequent prolonged droughts, the high latitude climate, and long distances to markets limits the number of farming options that can be economically and ecologically introduced.

Diversified (several different crops over time) and intense (every year) cropping systems that more efficiently utilize soil water have been shown to reduce costs as well as reduce water quality concerns (e.g., saline seeps). However, progress toward widespread adoption of diversified rotations using conservation tillage techniques has been slow within the Great Plains. Impediments to the adoption of conservation tillage and other technologies (e.g., precision agriculture) include: a general unwillingness to change established practices, limited risk/benefit information when adopting new technologies, and increased short-term weed and pest problems. Increasing crop diversity is constrained for both rainfed and irrigated growers by the scarcity of economically viable alternative crops, higher input costs, increased initial equipment expenditures, inadequate technological expertise and few long-term regional field-scale studies demonstrating economic and ecological advantages or sustainability. Nevertheless, opportunities for alternative crops are improving as a result of the construction of a new 1.5 M bushel malting barley grain handling facility and a proposed 17 M gallon/yr ethanol production plant (corn) in the MonDak region.

Diverse cropping systems entail more complex management and thus carry a higher level of risk. Research is needed to: understand the complexity of these systems (soils, crops, fertility, water and pests); to quantify the economic and environmental benefits of strategies that reduce risk, to determine how these and other alternative crops will fit into current farming systems, and to learn how to take advantage of conservation practices (e.g. zero or limited-tillage, targeted nutrient and pesticide applications) that reduce costs. The potential of developing new market opportunities that encourage diversity will significantly increase once these issues are successfully addressed.

Irrigated and dryland crop rotation systems have traditionally relied upon substantial inputs of agrochemicals and tillage. However, economics and environmental issues are forcing changes to include more alternative crops (i.e., malting barley and corn), reduced use of agrochemicals and less tillage. New approaches are needed that minimize environmental impacts and increase net profit margins. Thus, the development of scientifically-sound, diverse, intense (cropped every year) irrigated and dryland systems that; reduce reliance on a limited number of major cash crops, ecologically alleviate pest problems; better manage soil water and nutrients, improve soil structure and productivity, and reduce farming input costs (including minimizing tillage) are needed to ensure the continued economic and environmental viability of the upper Missouri River Basin of the Northern Great Plains (NGP).

Even though there is abundant, unappropriated water for irrigation development in the upper Missouri River Basin, major conflicts are inevitable between agriculture and other users regarding environmental issues, downstream flows and water quality. In addition, energy costs for pumping are rapidly escalating greatly affecting the economic sustainability of these enterprises. New and improved management strategies and practices are needed to reduce surface and groundwater contamination from agricultural lands. Improved irrigation practices are increasingly important to enhance water quality, conserve water, soils and energy, and sustain American food production for national strategic, economic and social benefits. Innovative irrigation techniques and management systems are needed to increase the cost-effectiveness of crop production, improve water quality, reduce soil erosion, and reduce energy requirements while enhancing and sustaining crop production and water use efficiency. Maintaining crop production through the more efficient use of rainfall and irrigation is critical to overcoming these problems in both space and time.

Approximately one third of all irrigation in the US utilizes self-propelled center pivot and linear move irrigation systems (Irrigation Journal, 2001). It is estimated that only about 28,000 hectares in the MonDak region are currently irrigated with self-propelled systems. However, as labor becomes more limited and the farming population ages, it is expected that several thousand more acres will be converted from surface to self-propelled irrigation systems within the next ten to fifteen years. In addition, as much as 200,000 hectares of land could be converted from dryland to irrigated production in the MonDak region. Dryland fields close to the Yellowstone and Missouri Rivers suitable for irrigation typically require pumping lifts from 50 to 200 m and have pronounced topographic relief. Conversion of these areas to irrigation will likely utilize self-propelled center pivot and linear move irrigation systems. Management of efficient self-propelled irrigation systems must account for specific crop, soil characteristics, and field topography to maintain economic advantages and profitability while minimizing negative environmental impacts

One critical means to help ensure the success of more diverse and intense farming enterprises is the development of reliable and timelier information on field and plant status that can be integrated into the decision-making processes. Research needs to focus on the development of spatial and temporal management approaches (including models) that address site-specific crop water, nutrient and pest management requirements in real-time. Achieving these goals and facilitating their integration into both dryland and irrigation farming enterprises will require much additional knowledge. However, a more comprehensive understanding of farming systems should result in substantial labor, water and energy savings and minimize agrochemical losses to surface and ground water. Plant models capable of predicting the physiological needs of a crop over space and time tend to be complex and impractical for real-time farm management. Furthermore, most of these models are point models that are not sensitive or robust enough to adequately predict site-specific plant needs across a field in a timely fashion. Simpler, more appropriate models for real time scheduling might be used, but will likely need frequent updating via automated, field-based sensor systems to readjust model parameters. Such sensor systems could include canopy microclimate monitoring, soil water status, plant reflectance characteristics, video cameras and other remote sensing technologies. More robust and accurate methods are needed to estimate or indirectly measure crop status for improved modeling accuracy.

No-till, conventional wheat-fallow tillage systems, and irrigated cropping systems are all impacted with persistent weed problems (e.g., green foxtail, wild oat, herbicide resistant kochia, and numerous other annual and perennial weeds). Biologically based integrated pest management (BIPM) weed control programs are needed to solve these problems. The level of research needed to address weed issues in diversified, intense cropping systems is challenging and complex. For example, weed control efforts in minimum till dryland systems are typically less reliable than conventional or irrigated cropping systems due to a restricted set of herbicide options combined with limited tillage and crop alternatives. But it should be possible to take advantage of between-year crop and management interactions by varying planting dates, planting configurations, cultivars, cultural and spray programs. Research is specifically needed to determine short-term means for controlling weeds at the onset of low-till or no-till farming efforts. Likewise, ecologically based weed control methods are desperately needed in irrigated cropping systems. Research must focus on lowering pesticide use through better sequencing of crops and better application timing, which will reduce weed seed viability and weed competitive advantages.

The role that various soil organisms play in overall soil health (e.g. residue nutrient cycling, soil aggregation and soil structure) needs to be more thoroughly understood to develop management strategies that can sustain and enhance soil productivity. Certain pesticides can have a negative impact on the soil biota, thereby reducing nutrient cycling and lessening soil aggregation. A better understanding of the functions of soil microorganisms in altering weed seed viability and soilborne pathogen survival is also needed. These insights may improve management practices (e.g. reduced chemical use) and improve soil quality by maintaining the natural resilience of the soil ecosystem. This proposed research should also develop some much-needed quick and reliable indicators of soil quality trends. We believe that integrated, intensive dryland and irrigated farming practices can be developed that improve soil quality by minimizing soil disturbance, the rate of mineralization of plant residue and soil OM, and help maintain good soil structure.

Traditional wheat-fallow cropping systems (conventional tillage) has led to reduction in soil OM content and declines in soil quality and productivity, resulting from increased nutrient mineralization of plant residues and wind erosion. These trends can be reversed by the annual addition of plant residues (above and below ground) and reducing the rate of nutrient mineralization. Fallowing the land also reduces soil OM because of a lack of crop residue inputs. Therefore, research is needed to maintain soil organic matter by increase plant residue inputs and reduce mineralization rates utilizing conservation tillage techniques and new cropping strategies. This necessarily includes better understanding of the impact of various cultivation techniques on soil microbe populations and competitiveness, and to determine how the effects of soil disturbance can be mitigated by actively managing the total microbial population.

Sugarbeets are one of the most important irrigated crops in the NGP. Cercospora leaf spot (CLS), caused by *Cercospora beticola* is one of the major diseases of sugarbeets in the region. Severe disease pressure results in substantially reduced sugar content, and the need for increased pesticide applications can significantly reduce net farm income. However, the pathogen has developed resistance to a number of chemicals and others chemicals are being lost by new regulations. Traditionally, sugarbeet farmers rotate spring wheat with sugarbeet crops in a two-year rotation. Newer crops (i.e., malting barley) are being added to the sugarbeet/wheat rotation. However, barley and wheat are both susceptible to Fusarium head blight (FHB) that reduces crop yield by causing the plant to reallocate resources and reducing grain quality (mycotoxin contamination). High humidity levels within the plant canopy are created by overhead irrigation that leads to increased incidence of both FHB and CLS. Thus, research is needed to develop methods of early detection and evaluate the potential of biocontrol in reducing both CLS and FHB. This could greatly reduce applications of pesticides, improve ecological sustainability, reduce production costs and help ensure a safe food supply.

The **Problem to be Solved** by this proposal is the critical need for scientifically-based means to increase net farm productivity, maximize agricultural water use efficiency, minimize agrochemical use, improve water and soil resources and maintain a healthy food supply. The regional goals are to improve NGP farm productivity and profitability and to reduce constraints to the adoption of advanced farming practices (utilizing a multi-disciplinary systems approach) that are based on sound agronomic, soil and water, and pest control science. The regional benefits of this work are important because similar research results from other geographic areas are not always applicable in this distinct climatic and edaphic region (semi-arid climate, very cold winters, short growing season and low soil OM levels).

The **NP207 Action Plan** states “balancing economic, environmental, and social demands requires a high degree of management skill and knowledge because every farm or ranch is a complex system of interacting components that exists in both a natural and socioeconomic environment.’ Cropping systems, agronomic management, water management, and pest ecology combined with spatial information sources and models are needed research areas to achieve that balance.

The proposed research is **Relevant to the Mission Statement of the NP207 Action Plan** by developing scientific knowledge about agricultural systems by studying the biological, physical, and chemical interactions of the systems components. Combining interdisciplinary and multi-location research efforts will contribute to the development of comprehensive databases, information retrieval and analytical tools, and decision support systems needed to understand system functions and the economics of farm management. Specific **NP207** outcomes of ASRU research include: 1) alternative pest control procedures that minimize production impacts and reduce agrochemical use, and 2) technologies that enhance the viability of existing agricultural and animal production systems and foster the development of new, more sustainable production practices. In particular, this research addresses the **NP 207** goal to develop agricultural systems that emphasize conservation, protect soil and water resources, improve pest management, minimize ecological disturbance, and encourage biological diversity (see **Appendix B** for more detail).

The proposed research directly addresses the Mission Statement of the **NP201 (water quality) Action Plan** to: “develop new and improved practices, technologies, and strategies to manage the Nation's agricultural water resources.” Specific expected outcomes of ARSU research related to the **NP201 Action Plan** include: 1.) Improved strategies that enhance and safeguard the quantity and quality of national water supplies, and 2.) Development of sustainable agricultural systems that more efficiently use water resources, reduce the impacts of soil salinization, ground water depletion, and water contamination. It is important to note that research in this CRIS will also provide flexible, yet sustainable, management strategies that directly support the **202 (soil management), 303 (plant diseases) and 304 (crop protection) National Programs.** Explicit outcomes will include; information specific to the crop-soil-water interface, determining best management strategies that maintain high crop production potentials, reduced dependence on agrochemicals, reduced incidence of pest outbreaks, increased farming efficiency, conservation of water quantity and quality, and further definition of the important role soil microbes and other organisms play in maintaining and improving soil conditions.

Potential Benefits to producers, action agencies, agro-industries and other stakeholders are systems that improve water use efficiency, reduce water and soil degradation, and advance the long-term sustainability of irrigated and dryland agriculture in the NGP. Other benefits include; the reduction in economic and environmental costs (associated with the proper use of pesticides and fertilizers) and more efficient use of limited soil and water resources. The bottom line is the development of more profitable and environmentally friendly farming practices that maintain an affordable and safe food supply.

Anticipated Products (next 3-5 yrs) from this research are the: 1) Initial development of biologically-based, sustainable weed and disease management strategies; 2) Initial development of soil and residue management practices for irrigated and dryland production that improve soil water retention and minimize the use and negative impacts of agrochemicals; 3) Initial development of sensor-based irrigation scheduling methods for enhanced management of self-propelled water application systems; 4) Development of low-cost and fast tests for quantifying soil-aggregating microorganisms, enzymes, polysaccharides and OM decomposition rates (part of the ARS National Soil Management Assessment Framework); 5) Development of fact sheets on improved tillage management techniques and alternative crop rotations that optimize soil health, soil biological diversity, biologically-based cropland weed control, residue management, water quality and net returns (technology transfer); 6) Extension outreach through participation in grower-directed, technology transfer activities (field days, grower meetings, etc.), and 7) Publishing scientific manuscripts documenting experimental findings in leading disciplinary journals.

The **Customers and Stakeholders** of this research are irrigated and dryland producers, agricultural consultants, commodity organizations, scientists, and state and federal agencies (i.e. USDA-NRCS, Bureau of Indian Affairs (managing Native American farmlands), US EPA (BMPs), state departments of agriculture, land grant universities, and tribal colleges) that investigate, encourage, develop or manage production farming practices in the NGP. The general public will benefit through improved environmental quality and safer food supplies. A broad cross-section of regional agricultural interests comprises the NPARL customer focus group. This group reviews findings and provides guidance on emerging customer needs and future research directions.

SCIENTIFIC BACKGROUND

Cropping systems. The small grain summer fallow/dryland cropping system was originally developed to conserve water and nutrients in one year for use in the next. However, inefficiencies in storing water under fallow, development of effective chemical weed controls and increased use of nitrogen fertilizers have led to a reduction in summer fallow and a rise in continuous (without fallow) cropping in some areas. Over the past 25 to 30 years, research in the Great Plains has shown that the long-standing practice of alternating summer fallow with spring wheat production is inefficient in storing soil water (Greb, 1979; Greb et al., 1979), has caused the formation of saline seeps (Brown et al., 1983; Diebert et al., 1986), and promotes soil organic matter (OM) loss (Haas et al., 1957). Comparisons of wheat-fallow systems with more intense every year dryland rotations in the region have shown greater water-use-efficiencies and resulted in biological yield advantages over wheat-fallow (Peterson et al., 1996; Anderson et al., 1999; Nielsen et al., 1999). Similar work has been done at Sidney (Aase and Reitz, 1989) with the stipulation that greater cropping intensity be accompanied by a reduction in tillage intensity to allow crop residues to remain on and below the soil surface. The introduction of minimum till or zero-till continuous cropping practices further conserves soil water, provides improved microenvironments for seedlings and soil biota, and increased precipitation use efficiencies. Weed management has always been an economic and environmental problem in agriculture, but control options are especially limited on low value crops (Farahani et al. 1998; Tanaka 1989).

The use of integrated crop production systems (ICPS), with multiple alternative crop options and rotations, increases the biological diversity of crops and soils. This “biologically dynamic” approach is advantageous to overall production in both the central (Nielsen, 1998; Anderson et al., 1999) and northern Great Plains (Johnston et al., 2002; Aase and Pikul, 2000). Greater biological diversity in a rotation disrupts pest cycles and promotes more efficient use of soil water and nutrients (Vigil et al., 1997). Viable alternatives to small grains (within the context of crop rotations) include pulse and oilseed crops; however, specific research is needed to examine many of the crop interactions occurring within this context (Miller et al., 2002; Johnston et al., 2002). Successful design of rotations for the region requires an understanding of previous-crop water and nutrient use, and its effects on following crops (Nielsen and Anderson, 1993; Westfall et al., 1996). Tanaka et al (2002) presented a framework for "dynamic" cropping systems that utilizes a variety of soil and plant management practices (with a diversity of crop species) to reduce the risk of disease, weeds and insects. While these concepts were developed for dryland production systems, they should also apply to irrigated cropping systems.

Weed Management. Each year herbicides are applied to over 90% of the major field crops in the USA, and atrazine alone is applied to approximately 70% of the US corn crop (USDA, 2000b). This constitutes a substantial production cost. Management of weeds in agriculture fields with herbicides is under intense public scrutiny because of their potential negative environmental effects (especially on water resources). Public safety and ecological concerns have resulted in the banning of some pesticides (Moffat, 2001). Herbicides, more than any other type of pesticide, are being found in water quality studies and atrazine is often the principal contaminant (USDA, 2000a). In addition, the development of pests resistant to herbicide controls such as resistance to acetolactate synthase (ALS) inhibitors is a major concern. ALS is the target site for 44 different herbicides within 5 different chemical families (Mallory-Smith and Retzinger, 2003). In the MonDak area, ALS resistant kochia readily out competes seedling sugarbeets and other crops (Mesbah et al. 1994; Thompson et al. 1994; Weiner and Fishman, 1994). Other weeds such as green foxtail now have high levels of resistance to ALS inhibitors (Wolf et al. 2000) and other commonly used herbicides (Cranston et al. 2001). Much is known about ALS resistance effects on kochia physiology, genetics and pollen flow (Dyer et al. 1993, Christoffoleti et al. 1997, Gutierri et al. 1992, Gutierri et al. 1995, Mengistu and Messersmith 2002, Stallings et al. 1995), but very little is known about the impact of ALS resistant weeds on sugarbeet production, which relies on a limited number of herbicides. Research has documented that ALS-resistant kochia seeds differ biochemically from non-ALS-susceptible seeds, with resistant accessions having elevated levels of branched chain amino acids (Dyer et al. 1993).

Weed management is the highest cash expenditure in most dryland farm operations in the Northern Great Plains. Wheat-fallow systems under conventional tillage have significant problems with green foxtail (Spandl et al., 1999), wild oat (Lueschi et al., 2001), herbicide resistant kochia (Christoffoleti et al., 1997), and numerous other annual and perennial weeds (Thompson et al., 1994; Derksen et al., 2002). As farming systems become more complex (zero-tillage, diversification, intensification of crop rotations), herbicide options become fewer and less reliable, further complicating weed management (Anderson, 1999; Anderson et al., 1998).

Weed management is also the single greatest impediment to the adoption of dryland conservation (low-till or no-till) farming systems in the MonDak and Great Plains regions (Vigil and Nielsen, 1998; Nielsen, 1998; Norwood, 1999). A crucial topic with minimum till integrated crop production systems (ICPS) is the evaluation of ecological relationships between the target crops and weeds as a base for developing ecologically safe (cultural and biological) and affordable weed control practices. Farming practices such as different planting dates (Spandl et al. 1999) and fertilization practices (Anderson et al., 1998; Blackshaw et al., 2003) can increase a crop's ability to out compete weeds, increase water-use efficiency, and improve crop yield and quality.

New, innovative and less problematic long-term solutions are being sought. One approach is to develop and integrate cultural and biological weed management options (Anderson, 1999; Blackshaw et al., 2003) into viable farming systems (Derksen et al., 2002) for the MonDak region. This will require an ecological understanding of weed/crop competition (including weed economic thresholds) and biologically based integrated pest management (BIPM.) However, much of this work is still in the developmental stages (Holtzer et al 1996; Derksen, et al., 2002). Recent research stresses crop cultural management and crop diversity as important components in controlling weeds (Derksen, et al., 2002). Additional studies have shown three or more crop cultural practices (e.g. seeding rate, modified row spacing, and crop variety selection), when used together, can greatly assist in controlling weeds and reducing herbicide use (Anderson, 1999; Anderson, 2000; Anderson et al., 1998; Nielsen and Anderson, 1993; Westfall et al., 1996; Tanaka et al., 2002).

A limited amount of research has focused on the soil weed seedbank and its response to different management strategies. Research has established that weed seedbanks are influenced by crop rotation (Entz et al. 1995; Kegode et al. 1999) and tillage system (Webster et al. 2003). Proper soil management can be used to increase the percentage of weed seeds that germinate and decrease the time period of weed emergence (Larson et al. 1958; von Polgár 1984, as cited in Hokansson 2003), thus reducing the number of times herbicides need to be applied and the timeframe (years) needed to effectively control many annual weeds. New soil/seed sampling approaches are now available that make it possible to process sufficient samples to determine the influence of ICPS on weed seedbanks and monitor weed population dynamics (Derksen et al 1998). These tools increase our understanding of soil seedbank dynamics, which in turn aids in the development of farming practices capable of controlling weeds without a disproportionate reliance on pesticides.

Irrigation Management. Over the past 50 years, the goal of center pivot and linear move irrigation design engineers has been to have the most uniform water application depths possible along the entire length of the lateral pipe, and they have been relatively successful. However, the terrain under these types of irrigation systems is often quite variable, causing system pressure (and water distribution) fluctuations along the lateral pipeline. Intermittent end gun operations also cause system pressure fluctuations that result in uneven water applications. While engineering solutions such as flow control nozzles or pressure regulators at each head have somewhat helped this situation, they are still not able to fully compensate for the effects of system pressure changes (Evans et al., 1995; James, 1982; and Duke et al., 1997, 2000). These factors not only affect the amount of water applied to a given area within the field, but they also greatly compound environmental risk when applying agrochemicals through the irrigation system. If fertigation is used, or if the water supply contains significant nutrients, the nutrient distribution will also not be uniform (Evans et al., 1995; Duke et al., 2000).

In addition, soils are heterogeneous (chemically & physically) and water-holding capacities are not uniform across fields (Burden and Selim, 1989; Agbu and Olson, 1990; McBratney and Webster, 1983; Han et al., 1993). Consequently, even with relatively uniform applications, surface runoff or ponding can occur at the lower elevations within a field. Shallow subsurface water transport along soil compaction layers and within-field surface runoff from higher elevations also contribute to saline seeps, nutrient leaching, and soil erosion (Han et al., 1996a, 1996b; Howell et al., 1995; Suddeth et al., 1996). The net result of these factors is a considerable variation in yield and agrochemical leaching across the field as well as reduced crop quality and higher pumping costs for unneeded water (Evans and Han, 1994; Han et al., 1995; Mulla et al., 1996; Mallawatantri and Mulla, 1996).

One possible solution is the development of site-specific irrigation technologies that can compensate for changing system pressures, heterogeneous soils and variable topography by applying water much more precisely to specific areas of a field. Center pivot and linear move irrigation systems are particularly amenable to site-specific approaches because of their current level of automation and the large area covered by a single lateral pipe. These types of irrigation systems provide a high level of water control and can also serve as a sensor platform for real-time water applications. Automated, real-time irrigation technologies also make variable rate agrichemical and water applications possible. Several innovative technologies have been developed to variably apply irrigation water for whole field management under self-propelled systems. Most of these approaches use standard, off-the-shelf components with the research effort directed towards developing appropriate control algorithms (Roth and Gardner, 1989; McCann et al., 1997; King and Wall, 1997; Camp et al., 1996; Sadler et al., 1996; King and Kincaid, 1996; Fraisse et al., 1992; Evans et al., 1996a; Duke et al., 1998; Harting 1999). Anticipated benefits of these systems are many including the ability for an irrigator to meet the specific needs of a crop in each unique zone within a field, which can optimize crop yield, crop quality, and maintain environmental health (water conservation and reduced agrichemical use) while reducing costs.

Nutrient Management. Nitrogen management is a major factor in the quality of sugarbeets and small grains. However, the potential benefits of this relatively inexpensive amendment to the crop can result in excessive applications. The mobility of the NO_3-N ion through the soil and the large amount of N fertilizer used makes nitrogen management particularly problematic (Smika et al., 1977). To avoid the risk of yield reduction, farmers may over-irrigate and over-fertilize their crops. However, the risk of contaminating surface and subsurface water resources greatly increases under this type of management. Emerging site-specific (variable rate) fertilization technologies can potentially reduce the excess use of fertilizers while maintaining crop production. Thus, controlling surface applications and minimizing water and agrochemical loss below the crop root zone are the most cost-effective methods of ground water protection (Hergert, 1986; Ritter, 1986; Power and Schepers, 1989; Fletcher, 1991; Watts et al., 2000).

Sensing Plant and Soil Status. Crop water use is soils and region specific and the spatial distribution of water across a field is the primary limiting factor to crop quality and yield in the NGP. Remote sensing (RM) techniques can provide a wide variety of information concerning the spatial and temporal variability of plant water and nutrient status. Remotely derived vegetation indices have been used for many management applications because they correlate well with green biomass and leaf area. These indices are often used as indicators of plant health and vigor; however, they lack the diagnostic capability for identifying particular types of stress (Pinter et al. 2003). Spectral indicators of crop development and canopy size available through vegetation indices can be used as input or as feedback to weather- and process-driven plant models (Wiegand et al., 1986). Jackson et al. (1980) showed similarities between the mean crop water use coefficient (K_{co}) for small grain and the ratio of the perpendicular vegetation index (PVI) of wheat to the PVI of wheat at full canopy cover. Heilman et al. (1982) developed relationships between the K_{co} for alfalfa and percent canopy cover and between the PVI and percent canopy cover to infer the K_{co} for alfalfa from spectral estimates of canopy cover. Bausch and Neale (1987) and Neale et al. (1989) developed reflectance-based crop coefficients for corn based on the normalized difference vegetation index (NDVI). The NDVI appears sensitive to crop growth anomalies, hail damage, and stress caused by water, disease, insects, and nutrients. Several approaches have shown good relationships between ground and aerial sensor data and field nutrients, such as nitrogen (Schepers et al., 1992; 1996; Blackmer et al., 1993; 1994; 1996a; 1996b; Blackmer and Schepers, 1996). However, the integration of traditional RM data with stationary and/or mobile field based sensor systems with computer models and controls for real time management is lacking. Other potential management contributions resulting from RM data include salinity stress, nutrient and pest management, and yield prediction (Wiegand et al., 1996; Yang and Anderson 2000; Richardson et al., 1996).

Soil Quality, Soil Structure and Nutrient Cycling. Soil structure and aggregation are important to plant growth and production. Various microbes play an important role in the formation and maintenance of soil structure (Lynch and Bragg, 1985). Microflora, in particular fungi, contribute directly to the formation and stabilization of soil aggregates through hyphal entanglement of soil particles and deposition of extracellular polysaccharides that bind soil particles together (Tisdall, 1991). In general, studies of the role of fungi in soil structure have been few, mainly because of the perceived difficulty of analysis. However, new immunoassay techniques are now available that can identify microbes at the order, genus, and even species level (Caesar-TonThat et al., 2001).

Soil OM (soil organic C and N concentrations) is a key indicator of soil quality and productivity because of its favorable effects on soil physical, chemical, and biological properties (Bauer and

Black, 1994; Doran and Parkin, 1994; Low, 1972; Tisdall and Oades, 1982; Dormarr, 1983; Gupta and Germida, 1988; Elliot, 1986). It plays critical roles on nutrient cycling, water retention, root growth (Sainju and Kalisz, 1990; Sainju and Good, 1993), erosion control, plant productivity, and environmental quality. Consequently, plant growth will be diminished when improper cultivation practices decrease pore space, reduce size distributions of water stable aggregates (WSA), soil/root hair contact and increasing soil bulk densities (Wienhold and Halvorson, 1998). Mollisol soils (mostly Typic Argiborolls), common to the MonDak region, are easily compacted at medium to high moisture contents, further degrading soil structure. Increasing soil OM also helps reduce the deleterious effects of global warming by sequestering atmospheric CO_2 and some other greenhouse gasses (Lal and Kimble, 1997; Paustian et al., 1997).

Tillage practices can negatively impact both the physical structure and microbial components of the soil, and reduces soil organic C and N by increasing residue degradation, disrupting soil aggregation, and increasing aeration (Dalal and Mayer, 1986; Balesdent et al., 1990; Cambardella and Elliott, 1993). Similarly, fallowing reduces organic C and N by not replacing organic matter lost by mineralization through crop residue addition (Grant, 1997). In contrast, practices that reduce residue incorporation and aggregate degradation, such as no-till or strip tillage, may conserve and/or maintain soil organic C and N (Doran, 1987; Havlin et al., 1990; Franzluebbers et al., 1995b) and increase microbial biomass (Linn and Doran, 1984; Gupta and Germida, 1988; Havlin et al., 1990; Drury et al., 1991, Caesar-TonThat et al. 2001). Higher cropping intensity minimizes OM loss by sustaining annual residue returns to the soil (Sherrod et al., 2003). Holland and Coleman (1987) also reported that aggregation resulting from fungal hyphae was more easily established in soils that were minimally disturbed, and that fungi generally dominate in soils under reduced tillage.

Recovery of desirable soil structure (indicated by size distributions of WSA) under no-till may take as long as 50 years or more (Tisdall and Oades, 1980; Dormarr and Smoliak, 1985*)*. Changes in soil organic C and N as a result of management practices occur slowly because of their large pool size and inherent spatial variability (Franzluebbers et al., 1995a; Salinas-Garcia et al., 1997). In contrast, <u>active fractions</u> of soil organic C and N, including potential C and N mineralization (PCM and PNM) and microbial biomass C and N (MBC and MBN) are indicators of microbial activity, N mineralization potentials, and inorganic N. However, these vary seasonally due to changes in plant residue amounts, management practices (Franzluebbers et al., 1995a; Salinas-Garcia et al., 1997), rhizodeposition of organic materials from roots (Buyanovsky et al., 1986), and seasonal changes in soil moisture and temperature (Kaiser and Heinemeyer, 1993). Similarly, particulate organic C and N (POC and PON) fractions are regarded as <u>intermediate</u> pools of soil organic C and N (Beare et al., 1994; Franzluebbers et al., 1999). These fractions have been identified as early indicators of changes in soil organic C and N levels that influence soil aggregation and nutrient dynamics in the soil (Franzluebbers et al., 1995a; 1995b; Salinas-Garcia et al., 1997; Six et al., 1999).

There is considerable evidence supporting the involvement of polysaccharides in soil aggregation (Clapp and Emerson, 1965; Cheshire et al. 1983; Martin, 1945; Robert and Chenu 1992; Clapp et al. 1962; Tisdal and Oades, 1982; Angers and Mehuys, 1999; Haynes and Francis, 1993). Wright and Upadhyaya (1998) isolated a glycoprotein, produced by Glomales (phylum Zygomyceta [vascular arbuscular mycorrhizal fungi]), which is highly correlated with soil aggregate stability. However, these obligate fungi cannot be cultured in the laboratory because their survival depends on the photosynthetically derived carbon provided by their specific host plants. Thus, it is also important to investigate the very large populations of non-obligate fungi (easily propagated in the laboratory) for their role in soil formation and aggregation and to help understand the mechanisms by which these fungi help bind or aggregate soil particles.

Polysaccharides that contain uronic acid groups (primary carboxyl [COOH]) have ion-exchange properties that, when in the presence of di- or trivalent cations, play an important role in binding clay particles into aggregates (Martin, 1971; Chenu, 1993). Extracellular polyuronic acids are produced by <u>plants</u> (Vermeer and McCully, 1982; Watt et al. 1993), <u>bacteria</u> (Clapp et al. 1962; Griffiths and

Burns 1972; Chenu 1989; Molope et al. 1987; Robertson et al. 1991; Robertson and Firestone, 1992; Skvortsov and Ignatov, 1998), and fungi (Tisdall, 1991; Singleton et al. 1990; Caesar-TonThat, 2002.). Using electron microscopy and staining of soil fabrics, Foster (1981) found that polysaccharides coat clay platelets and occur in crevices of submicron size within mineral aggregates, which helps explain how microbial polysaccharides stabilize clay aggregates.

Limited studies have shown that long-term tillage reduces soil carbohydrate content and impacts soil structure (Cheshire et al. 1984; Robertson et al. 1991; Puget et al. 1994; Dormaar, 1984; Hu et al. 1995; Beare et al. 1997; Murayama, 1984; Schlecht-Pietsch et al. 1994). There are few reports on the effects of different agricultural management practices on uronic acids used in soil aggregation. Lately, Kiem and Kogel-Knabner (2003) found that soil aggregates (200-250 um) from two different sites contained less galacturonic acids under conventional management with fertilizers than management without fertilizers. We believe that many of the complex biological, chemical, and physical processes involved in soil aggregation can be deduced by understanding the dynamics of the acidic polysaccharides. Furthermore, uronic acids can be easily measured, and should provide a reliable indicator of soil health once we understand the relationships between uronic acids and soil aggregating microorganisms (Caesar-TonThat et al. 2001), glomalin (Wright and Upadhyaya, 1998) and soil OM content.

Biotic and abiotic N dynamics are influenced by residue quality (e.g., C/N ratios), residue placement depth (e.g., surface vs buried), and various climatic and soil environmental factors (i.e. temperature, clay content and pH) (Barrett et al. 2002). Plant and microbial enzymes also play a key role in soil nutrient cycling (Kiss et. al. 1975; Ladd, 1978; Bahl and Agrawal, 1972; Tabatabai, 1994). Enzymes, primarily produced by microbes, accumulate in the soil as they are released from living cells, disintegrated cells and enzymes bound to cellular constituents (Kiss et al., 1975). Several studies have been published on the potential use of enzyme activity as an index of soil productivity or microbial activity (Weaver et al. 1994; Dick et al. 1996) and as indicators of soil condition (Monreal and Bergstrom, 2000; Kandeler et al., 1999; Tscherko and Kandeler, 1999, Gupta et al., 1988; Klein and Koths, 1980). Additional research is needed to understand the complex interactions between enzymes and the surrounding plant and soil material in order to develop meaningful indicators of microbial status and soil physico-chemical condition (AKA: soil quality).

Plant Pathology. Chemical control remains the primary avenue for managing plant diseases. In 1979, Sharvelle reported that $60 billion of the world's 1974 food supply was lost to diseases, weeds and insects. More recently, Wrather et al. (2001) estimated that in 1998 ten countries (producing 97.6% of the world's soybean crop) lost 28.5 M tons (U.S. $6.29 trillion) due to plant diseases. However, many plant pathogens have developed resistance to pesticides. In addition, some effective chemicals (e.g. methyl bromide) are being banned due to health and environmental concerns (Moffat, 2001). The need for effective pest control is critical to modern crop production; however, new methods must be developed that conform to current socio-ecological guiding principles. Long before the advent of chemical controls, plant diseases and other pests were managed by crop rotations, plant diversity, livestock use, and other cultural practices (Sharvelle, 1979). Much of this once common knowledge has been lost to growers because of the changed emphasis to crop monocultures and a heavy reliance on chemicals. However, current trends and environmental regulations indicate that research must re-examine, remodel and reintroduce some old concepts into modern alternative pest management strategies (minimal chemical use) that use crop diversity, cultural, improved water management and other biologically-based technologies to better manage diseases and other pests.

Cercospora leaf spot (CLS) disease caused by the fungal organism *Cercospora beticola* Sacc., is one of the most important diseases of sugarbeets (*Beta vulgaris* L.). The disease has been reported wherever sugarbeets are grown (Bleiholder and Welzien. 1972) and results in significant losses of root biomass and sucrose content (Smith and Ruppel, 1973; Shane and Teng, 1992). Smith and Ruppel (1973) graded CLS disease severity on a scale ranging from one (low) to ten (high). Their findings indicated that a severity level as low as 3 could result in sugar losses of as much as 30%. Recent research by ASRU scientists has shown that laccase enzymes, produced by some bacteria and tricoderma and basidiomycetes fungi, detoxify cercosporin (toxin produced by *C. beticola*) and allows the *C. beticola* pathogen to be attacked by various biological agents (Caesar-TonThat et al., unpublished, 2003.) This finding opens the door to several new biological approaches for the control of C. beticola and as well as many other plant pathogens. Research at other laboratories (e.g., ARS, Fargo, ND and MSU, Bozeman, MT) has focused on identifying and understanding how to genetically introduce host-plant cercosporin resistance into sugarbeet. However, no research is evaluating the use of cercosporin resistant antagonists for CLS control.

Severe incidences of CLS disease often require multiple applications using different fungicides to prevent large economic loss even when sound crop rotation practices are used. The current lack of effective cultural control methods suggests that other, yet-to-be-identified secondary hosts (e.g., other crops and weeds) can sustain *C. beticola* populations for many years. Several plants (e.g., *Beta* spp. including red garden beet, Swiss Chard and mangel-wurzel) have been identified as secondary hosts of *C. beticola*. Several weeds are also known hosts of *C. beticola* including *Chenopodium album* L, *Amaranthus retroflexus* L, *Malva rotundifolia* L, *Plantago major* L, *Arctium lappa* L and *Lactuca sativa* L (Vestal, 1933). Other common weeds such as mallow, bindweed, winged pigweed, wild buckwheat, and the common unicorn flower have also been named as alternate hosts. ASRU scientists have recently identified safflower, a widely grown dryland crop in the NGP, as an alternate host (Lartey, unpublished, 2003) of *C. beticola*. Clearly, these host plants can serve as an inoculum reservoir that maintains the organism through long periods, even when sugarbeets are not planted. Therefore area wide weed control and cropping programs may play a major part of long-term CLS management strategies.

As noted, spring wheat (durum) has been traditionally rotated with sugarbeets in the MonDak region. Recently, there has been a large increase in malting barley (replacing wheat in the rotation). However, both barley and wheat are susceptible to Fusarium head blight (FHB), a major threat to small grains around the world. Incidence of FHB reduces crop yield by limiting the plants photosynthetic capability and lowers grain quality by fungal mycotoxin contamination. Several *Fusarium* species cause FHB, but in North America, *F. graminearum* Schwabe (teleomorph *Gibberella zeae* (Schwein) Petch: synonym = *G. saubinetti*) are the predominant species (McMullen et al., 1997). High humidity levels within the plant canopy can increase incidence of FHB, and biological control options are a high priority for producers using overhead irrigation.

CSREES-CRIS SEARCH. A search of the CSREES-CRIS system using keywords of cropping systems, irrigation, dryland, water use, spatial variability, soil water, soil quality, water quality, weed ecology, no-till, IPM, integrated pest management, precision farming and precision agriculture showed that 83 different projects dealt with one or more of these topics. Inclusion of irrigation and dryland as keywords added 31 more. However, only the most pertinent programs are listed below.

A holistic approach to irrigated and dryland cropping systems is being pursued by the ASRU team and we are collaborating with colleagues at Montana State University (MSU) -Sidney (Bergman and Flynn) and North Dakota State University (NDSU) -Williston (Bergman and Staricka). A limited number of other projects are in process that use a holistic approach, including: *Dryland Cropping Systems Management for the Central Great Plains* (Vigil et al.); *Diverse Cropping Systems for the Northern Great Plains* (Krupinsky et al.); *Integrated Forage, Crop, and Livestock Systems for Northern Great Plains* (Hanson et al.); *Agricultural Practice Studies with Emphasis on Soil Tillage* (Keisling); *Integrated Management Technologies for Sustainable Irrigated Cropping Systems* (Alva et al.); *Sustainable Crop and Soil Management Systems for Dryland Pacific Northwest Agriculture* (Albrecht et al.); and, *Soil Management Systems for the Responsible Use of Natural Resources* (Busscher et al.). As can be seen, several locations in the High Plains are investigating agricultural systems that include tillage, rotations, crop densities and row spacing alternatives that respond to the length of growing season, crop water use demands, and soils particular to their regions.

A large number of projects are developing management zones and strategies for site-specific crop management, including: *Spatial and Temporal Management of Irrigation, Fertilizer, and Pesticides to Conserve Water and Protect Water Quality*. (Heermann et al.); *Irrigation methods, Technology and management for increased water use efficiency* (Evett et al.); *Optimizing Irrigation Management for Humid Climates* (Saddler et al.); *Water Management and Quality for Improved Agricultural Ecosystems in Humid Regions* (Florence, SC); *Managing Crop Production in Semi-Arid Climates with Variable Water Sources and Amounts* (Wanjura et al.); *Site-Specific Nutrient Management Strategies for Irrigated and Non-irrigated Maize* (Ferguson); *Improving Fertilizer Management and Recommendations for Precision Agriculture* (Hergert); *Developing Site Specific Approaches for Crop Nutrient Management in Irrigated Agricultural Systems* (Davenport et al.); *Optimizing Nitrogen Management for Corn (Blackmer); Site- and Time-Specific Crop, Tillage, and Weed Management for Sustainable Agroecosystems* (Hatfield and Colvin); and, *Site-Specific Fertilizer Recommendation Methods to Improve Nutrient Utilization* (Kitchen et al.). These studies are mostly directed towards rainfed agriculture, but there are a few directed at irrigated crop production. Work related to specific aspects of ASRU research is also being done in Europe and Australia.

Applicable ecologically-based weed and disease management studies include: *Precision weed management in dryland agricultural production in eastern and central Washington:* (Yenish et al.); *Reducing herbicide use through site specific weed management* (Wilkerson and Coble); *Why weed patches persist: Dynamics of edges and density* (Mortensen and Dieleman); *Development of site-specific weed control system* (Medin); *Sustainable agricultural systems based on ecological principles of crop, weed and insect pest management* (Riedell et al.); *Weed Biology and Ecology and Development of Sustainable Integrated Weed Management Systems for Cotton, Soybean, and Corn* (Reddy); *Crop and Weed Biology and Management in Short-Season/High-Stress Environments* (Forcella); *The Genetics of Pathogen-Barley Interactions (Edwards); Nonchemical Pest Control and Enhanced Sugarbeet Germplasm Via Traditional & Molecular Technologies* (Panella and Hanson); *Genetics, Population Biology, Management and Host Response Gene Expression to Fusarium Head Blight of Cereals* (Kistler et al.); *Biocontrol of Cercospora Leaf Spot with Bacillus subtilis. (Jacobson); and, Role of Cercosporin in Cercospora Pathogenesis* (Daub). The proposed, complementary ASRU project will build on the concepts of others and adapt the appropriate ideas to study in our specific environment.

Remote sensing is an important tool to the future of users adopting site-specific management, and ARS programs at Ft Collins, CO, Phoenix, AZ and Lincoln, NE are investigating these issues. There are also several projects developing sensors and evaluating tools for site-specific irrigation and nutrient management. The following projects are developing new tools, evaluation techniques and approaches that we can field test in our research: *Integration of new technologies for improved water management* (King*); Closed-Loop Precision Irrigation for Improved Water Management* (King et al.); *Variable Rate Sprinkler for Improved Irrigation and Chemigation Management* (Wood et al); *Cropping Systems & Sensing Technology Integration for Sustainable Site-Specific Management* (Sudduth et al.); *Precision Agricultural Chemical Application Technologies* (Miles); *Development and Analysis of Machine Systems in Precision Agriculture* (Ess); and, *Variability in Metering Devices Used in Site Specific Crop Management Schemes* (Bashford).

We are quite familiar with the work being done in each of the above programs and believe the work is complementary. We will be following their results, and work collaboratively whenever possible with these researchers to maximize resources and develop results applicable across the NGP.

APPROACH AND RESEARCH PROCEDURES

This CRIS involves eight scientists and many collaborators that represent a very broad range of disciplines focused on the long-term goal (10-12 yrs) of developing crop production methods and strategies for economical, sustainable farming enterprises in the NGP. Most of the ASRU scientists are relatively new to their positions (only one has been at NPARL for more than 4 years) and much of this work is just beginning. The primary thrust during the next four years (the duration of this proposal) will necessarily be on the establishment and initial assessments of these selected integrated crop production systems.

The ASRU is organized into three overlapping, flexible research teams focusing on 1) the E**cology;** soil, water, and crop, 2) M**anagement;** and, 3) the E**nvironmental** impacts related to specific long-term dryland and irrigated crop rotations (see **Figure 1, p 31**). The focus of this research is on: 1) improved management of pests, water and nutrients to increase net profitability, and 2) assessing the impacts of integrated cultural practices and cropping rotations on soil and water quality conservation and pest ecology. We are proposing to use pre-selected, diverse **integrated crop production systems (ICPS)** that are potentially acceptable rotations to growers (as per our focus group) using ecologically based cultural operations, management and crop rotations. **Figure A-1 in Appendix A** is a map showing the various research locations. These biologically dynamic cropping systems are expected to evolve over the life of the program as a result of research findings and grower input. We recognize that research must demonstrate the distinct socio-economic and ecological benefits of the intensive ICPS before farmers are likely to adopt any new management approaches. Most of the hypothesis presented below cover both dryland and irrigated systems. This research covers a range of common soil types and agronomic practices tested under both plot and field conditions. Each ASRU scientist also has supporting, individual short-term projects. Soil water probes will be gravimetrically and volumetrically calibrated using field samples and references. All primary field projects will have an ACCESS relational database established where each team member can enter their data and experimental notes which will include: crop, yields, crop quality parameters, soil properties with depth (e.g., CEC, pH, SOM, POM, total N, C, P, K, Ca, Mg, Na, HCO_3, CO_3, soil texture), sample and field electrical conductivity (EC), hyperspectral data, soil microbial biomass, selected soil fauna populations, weed/pest species/populations, soil water/nutrient/disease status, microclimate data, field/plot aspect & slope, global positioning system (GPS) coordinates, etc. These databases will be used with models and geographic information system (GIS) applications to enable comparisons between research sites, link remotely sensed and other data to collaborative modeling work, assist extrapolation of findings to other areas, facilitate team research and data exchange, enhance synthesis of diverse data, and help identify and formulate new research hypotheses. ArcInfo/ArcMap will be used as one means to integrate the diverse spatial coverage and point data, and will serve as one medium to help evaluate of potential cultural, fertilizer and pest management alternatives. During the cropping season, ASRU scientists and 9 technicians will hold weekly meetings to coordinate field data collection activities and keeping others apprised of their activities and progress (otherwise similar meetings will be monthly.) Automated measurements will be used as much as possible for routine measurements (e.g., microclimate, soil water), but will be supported by periodic manual readings. Progress will be reviewed by examining the results in formal and informal quarterly reviews. In addition, we need to be able to accommodate our partners in expanding cooperative research and to provide more synergistic opportunities. Additional grant funds that become available to ASRU scientists and partners will provide opportunities to expand our efforts in the search for appropriate technologies and strategies. Experiments and hypotheses may be modified to accommodate new technologies, criticisms, and unexpected results. Specific studies may be adjusted based on feedback from our focus group, cooperating farmers, action agencies, peer reviews, university partners and industry. This approach will provide flexibility in our efforts to identify and research appropriate technologies for crop production, water conservation, reducing energy expenditures, and improving water quality. As noted earlier, three scientists, new to ARS, have just been added to the ASRU and there has been little opportunity to solicit their input and incorporate their research expertise into this proposal. Dr. Lenssen (weed ecologist) reported December 29, 2003, Dr. Waddell (soil chemistry) arrived January 12, 2004, and Dr. Sainju (soil management) came on board March 8, 2004. General aspects of their proposed research are included in this document; however, more detail on specific approaches and procedures will be developed after they become established at the laboratory. We are also adding two more scientists in the fall of 2004 (agronomist and an agricultural engineer/soil physicist) to work primarily on irrigated crop production issues, and their contributions will greatly enhance all the cropping systems and water quality efforts that are outlined in this proposal.

Objective 1: *To develop diverse irrigated and dryland cropping strategies and technologies that increase farm profitability, productivity and soil and water quality while maximizing agrochemical, water and nutrient use efficiencies.* ***Hypothesis 1a**:* Integration of advanced tillage, water, soil, biologically-based weed and disease management, diverse crop rotations and improved ecologically-based cultural practices and strategies can increase yields; increase soil and crop quality; ***1a-1**:* Integrated nutrient, water and IPM systems can be developed that improve crop quality (e.g., sugar content, protein levels) and increase yields of NGP irrigated and dryland agriculture; ***1a-2:*** Conservation tillage and increased cropping intensity will improve soil quality and productivity by increasing organic matter content (soil organic C and N, POC, and PON), microbial activities (PCM and MBC), and N mineralization (PNM, MBN, NH_4, and NO_3); ***Hypothesis 1b**:* Ecological and minimum tillage ICPS will increase the abundance of microbial population functional units, soil enzymatic activity and polysaccharide production; ***1b-1*:** Populations of specific soil aggregating basidiomycete fungi are increased by minimum tillage treatments and diverse rotations; ***1b-2:*** Polysaccharides (i.e., uronic acids) play a major role in soil aggregation; ***1b-3*:** Minimum tillage and ecological ICPS increase invertase and xylanase and indirectly influence soil aggregation; ***1b-4***: Conversion of no till dryland to minimum till irrigated ICPS will decrease bacidiomycetes and increase bacterial diversity. ***Hypothesis 1c*:** The adoption of biologically dynamic pest management practices will reduce farm inputs and increase ecological sustainability. ***1c-1:*** Cultural and other management strategies to biologically reduce weeds that serve as alternative hosts for pathogens can reduce pesticide inputs for other crops; ***1c-2*:** Biologically-based IPM weed control at the farm and area level reduces area-wide crop disease incidence by removing or controlling alternate hosts of pathogens.

Experimental Design: Adequate fertilizer and micronutrients will be applied to meet pre-selected yield goals for each dryland and irrigated crop based on established MSU and NDSU guidelines although sugarbeets will follow the local sugar company's suggestions. Soil fertility samples will be taken in the fall (for the upcoming field season) and analyzed by both our own and/or approved commercial laboratories. Management practices will be analyzed for nitrogen use efficiency (grain or total biomass produced per unit of fertilizer N applied) and water use efficiency (grain or biomass produced per unit of water).

Dryland Systems Research. The main subobjective of this research is to determine, under dryland conditions, the impact of tillage, crop rotations and cultural management on crop yield and quality, soil quality, soil water use efficiency, nitrogen use efficiency, and weed competitiveness. (Dr Sainju will have primary responsibility for coordinating the dryland cropping systems program.) This work will focus on: 1) minimum till, and 2) continuous (every year) cropping. It will include quantifying the effects of selected farming and cultural management practices, soil management, crop diversity, and increased cropping intensity on the stability and sustainability of dryland agroecosystems. Collaborative dryland research, focusing on intensive small grain sequences will include 120 replicated plots at: 1) the Culbertson-Froid Farm (loamy soil) starting 2005; 2) the Rasmussen site (clay loam soil) starting 2004, and 3) on selected grower cooperators' fields (common dryland soils) later in the program (See **Appendix A: Tables 1& 2**).

Conventional farming practices in the MonDak Region include tillage with disk or sweep plow, preplant broadcast of nitrogen fertilizer, seeding at rates that allow for substantial tillering by cereals or branching by broadleaf crops, and application of pre- and/or post-emergence herbicides regardless of weed pressure. A "diverse" cropping strategy is defined as a crop rotation that is at least 4 years in length and includes various grasses and broadleaf crops with different growth habits such as cool- and warm-season production and rooting patterns. "Ecologically-based" farming practices depend on the position of a particular crop within each rotation. These include a reduction or elimination of tillage, banding of fertilizer blends at planting, planting at higher rates and decreasing row spacing to increase crop competitiveness shortly after emergence, delayed planting until after the first flush of weeds has emerged (and can be killed by a pre-plant herbicides or tillage), alternating planting times from year-to-year to attach different weed species, monitoring weed species and densities, spring vs after-harvest weed chemical burndown (e.g., Roundup®). The ecological treatments will also leave higher wheat stubble (e.g., 20-30 cm to catch more snow) with all the straw left in the field, whereas the conventional wheat will leave shorter stubble (6-8 cm) and the straw baled and removed (a common practice to increase short-term net economic returns.)

Crops included in the dryland ICPS will consider potential markets (grower acceptance), weather patterns, equipment needs, fertility requirements, and pesticide use (throughout the rotation sequence). Crop water requirements and rooting depth, which influence water and nutrient levels throughout the soil profile, are also important considerations when choosing crops for ICPS and their proper placement in the rotation. This ICPS research is a fundamental departure from current "conventional" crop management systems in the area. Typical grower cultural practice in the area includes broadcasting fertilizer, nominal seeding rates, and wide (e.g., 30 cm) row spacing. Conventional tillage by growers includes shallow wide sweeps with a rod or tandem disking with a harrow to firm the seedbed before planting. Alternating summer fallow with wheat is still practiced by more than 50% of the area's growers. Totally no-till farming is still uncommon.

<u>Cultural Practices (Sainju, Lenssen, Waddell, Caesar-TonThat, vacant Ag Engineer):</u> The combined effects of crop diversity and increased intensity (e.g., continuous cropping), cultural practices, crop rotations and soil water management on diseases and weed populations as well as soil and water quality will be evaluated. Replicated plot studies will be established in an RCBD (4 reps) in 2004 at the Rasmussen Farm and the Culbertson-Froid site (see **Appendix A**, **Tables 1& 2**) to evaluate the relative impact of diversified, intensive crop rotations and management on production and soil health. The four rotational treatments (e.g., row spacing, fertilizer placement, planting times and seeding rates) at both dryland sites will be split to compare both conventional tillage and no-till. We are using wide sweeps with a rod packer as conventional tillage. Tilled continuous spring wheat will be the control. All crops except corn will be planted in rows spaced 20 cm apart, using a custom-built plot seeder/grain drill, which will have the capability of banding fertilizer below and offset from the seedbed on both till and no till. Corn will be planted using a modified JD 750 no-till planter in rows either 60 cm (ecological) or 90 cm (conventional) apart. All tillage will be in the spring.

Weed ecology research (Lenssen and other regional researchers) will include weed and weed seedbank composition and densities, ecology and biology in several dryland crop rotation studies as well as independent and collaborative field and greenhouse trials with scientists in soil management (Sainju), soil fertility (Waddell), soil microbiology (Caesar-TonThat), plant pathology (Lartey), and entomology (Blodgett/O'Neill). Research will investigate a number of cultural weed management options relevant to diversified zero-tillage, dryland systems, including planting date, fertilization methods and levels, rolling to increase weed germination to lower seed banks, incorporation of non-sprayed annual forages, and grazing livestock (in collaboration with growers) during fallow periods. Data collected from these studies will include weed species identification, composition, densities, distribution and biomass at the key life stages of crop. This information will be compared with crop yield and quality, soil water use, soil quality, and changes in the relative abundance of weed populations. Results from these smaller, shorter-term (2-3 years only) studies will be used to improve weed management (e.g., wild oat, kochia, green foxtail) in diversified rotations using scientifically sound approaches that control weeds, reduce herbicide use, and limit crop/weed resource competition.

Crop and weed density, biomass, reproductive tillers, and seed or pod densities will be determined by hand-sampling two randomly selected 0.5 m^2 areas within each of 300 seeded plots at the two dryland research sites. Grain yield estimates will be acquired using a plot combine to harvest a minimum of 12 m^2 area. Crop quality measurements will include seed protein and 1000-kernel weights (grains), oil content and color (oil seed crops) from combine-harvested samples following cleaning with screens and air. Harvest index, calculated as grain yield/aboveground biomass, will be determined for each plot. Soil water content will be measured in each plot (one access tube per plot) with a neutron moisture meter (field calibrated CPN Model 503DR) in addition to other sensors that may be present. Soil water will be measured at planting and harvest to a depth of 180 cm in 30cm increments in the dryland plots and to at least 120 cm in the irrigated plots.

Irrigated Systems Research. Irrigation research will be directed towards sugarbeet, potato, and small grain crop sequences under self-propelled irrigation systems (center pivot and linear move). The major effort will focus on overhead systems rather than surface irrigation even though most sugar beets in the area are grown under furrow irrigation. However, there is a high potential for large increases in center pivot sprinkler acreage in the next 10 years. Integrated irrigation research (precision linear move sprinklers) includes replicated plots (see **Appendix A: Tables 3 & 4**) at: 1) the **MSU Eastern Agricultural Research Center (EARC)** research farm (4 ha) near Sidney, MT (conservation tillage/irrigation method/crop rotation interactions) on clay soils and a shallow water table; 2) the **NDSU *"Mon-Dak Irrigation Research and Development Project Farm*"** in the Nesson Valley (16 ha) on sandy soils and a deep water table, and 3) grower cooperators' fields on common irrigated soils. Plot sizes for the irrigation research projects will be approximately 15 m X 25 m with four replications at both the MSU-EARC and NDSU locations. Non-sampled plot border/buffer areas will be at least 3 m into the plot to eliminate edge effects. (Dr. Evans will coordinate overall irrigation related research.)

Throughout the growing season, ASRU scientists will use biweekly soil samples and plant nutrient (petiole) samples to monitor plant growth under differing moisture conditions. Aerial remote sensing information will be acquired throughout the growing season (e.g., 4 times throughout the growing season) and related to ground plant sample data (especially plant nitrogen status) and hand-held hyperspectral radiometer data. The development of relationships between the ground samples and aerial hyperspectral imagery will be used to project findings across the wider region. Validation of the relationships developed from the plot data will be conducted in grower fields using the sampling approaches listed above. Soil water will also be measured by a network of electronic sensors (e.g., 30 cm long Decagon $EcH_20^{®}$ capacitance probes and/or Watermark® soil matrix sensors) tied to small dataloggers with spread spectrum radios to provide real time monitoring and feedback. Sensors will be placed vertically and centered at about 30 cm and 90 cm depths in the crop row. The electronic soil water probe data will be supported with locally field calibrated CPN Model 503DR neutron moisture gage measurements (15 cm increments) to the 1.2-m depth in the crop row on a biweekly basis. Recording tipping bucket rain gauges will also be placed at each soil water monitoring site with the top of the 20 cm wide gauge at canopy height to monitor rainfall/irrigation amounts and timing. Soil moisture and rain gauge values will be used to verify adequacy of irrigation scheduling, measure applications and modify irrigation amounts if necessary.

Two 0.5 m^2 samples will be hand-harvested from within each plot to quantify total aboveground dry matter, weed biomass, crop and weed reproductive tillers, and weed seed production. Sugarbeet and potato samples will be a total harvest from a 2 m X 15 m in the center of the plot area. Combine harvest data for cereal crops will be collected from three swaths using a 1.52-m wide Kincaid plot combine (swath lengths of approximately 15 m length). Total yield areas will be subsampled (n=10) for quality and defects. Sugarbeet samples will be assessed for quality (e.g., specific gravity, size distribution, length, brie nitrates, sugar content) and tons produced. Yields, protein content, kernel size distributions and color will be determined for barley and wheat samples. Potato analyses will include yields, tuber size and shape, specific gravities and assessed for internal defects.

Cultural Practices (vacant Agronomist, Lenssen, Evans, Waddell, Lartey, Caesar-TonThat, vacant Ag Engineer). Unless otherwise specified, agronomic practices and crop management will be similar to those commonly used for high-yield on-farm crop production in the Northern Great Plains. All irrigated plots will be treated with a Dammer-Diker™ to create small pits in the furrows to ensure that water stays on plots after the last cultivation, if needed. In addition, poylacrylamides (PAM) or other soil amendments may also be used to reduce off-plot water movement and soil erosion. Herbicides will be the primary method of weed control and supplemented with early season cultivation or hand removal if needed. Control of weeds, insects and diseases will be according to the published standards produced by MSU and NDSU scientists. Commonly used crop varieties with high yield potentials will be selected, and they will be fertilized to meet realistic yield goals.

Weed seedbank sampling cannot be done on an annual basis on all plots due to the amount of time required to process samples, but would generally be done every 3 or 4 years, depending on the rotation length of each experiment. The Nesson Valley (NDSU) irrigated sugar beet rotation study will be sampled for weed seedbank density and species every third year. Weed seedbank density will be evaluated for key weeds (e.g. kochia, green foxtail and redroot pigweed in the sugarbeet and potato crops) each year after planting by collecting and compositing 25 random samples per plot. This data will allow us to track the average number of seeds (by species) in each plot and statistically determine differences among plots that result from the various treatments.

Water Management (Evans, Waddell, vacant Agronomist, vacant Ag Engineer). Linear move systems are being used for this research because we can duplicate the water application characteristics of larger center pivot systems, in a much smaller area. An air-activated solenoid will control water application rates for each sprinkler head. The individual sprinkler heads will operate in groups equal to plot widths to meet water requirements of the different crops included within the experimental design (e.g., barley vs. sugarbeets). Water applications will be controlled at the generator cart by a commercial programmable logic controller (PLC; Seimens Model 226). The controller will adjust the amount of water being applied to each location of the field (manual override is possible). Water applications will be equally split by area within the EARC linear move system using either the mid-elevation spray application (MESA) heads or low energy precision application (LEPA) heads. The MESA heads (Nelson S3000/yellow plate/#29 nozzles) will apply water approximately 0.5 m above the crop canopy with sprinklers about every 3.3 m. The LEPA system (Senninger LDN bubblers) will apply water between each row at about 12 cm from the soil surface. Locations of both MESA and LEPA plots will be varied depending on the experimental design, but both will apply equivalent depths per pass. The Nesson Valley site will all be MESA heads.

Irrigations will be initiated when the cumulative crop evapotranspiration (ET_c) estimates have reached either 15 or 30 mm adjusted for approximate application efficiencies of 80% for MESA and 90% for LEPA. ET_c replacement requirements will be calculated from on-site weather data using the FAO-56 procedures (Allen et al., 1998). Water applications will be controlled using maps (frequently updated) generated from plot maps and crop specific ET_c from weather station data for each area of the field depending on the linear move's position. Raven DGPS units (mounted in the center of each system) will determine the exact position of both linear move systems as they move across the field. When necessary, pre-plant and emergence irrigations will be applied with the MESA spray heads. Logistically, it will be necessary to run the irrigation system, even when some plots (or zones) do not need water (zero applications). Therefore, the designed volume capacities of both systems were increased to about 1.45 L s^{-1} ha^{-1} (~ 9 gallons min^{-1} ac^{-1}) of water to provide extra flexibility, and precision controls will change applications by location in the field. Irrigation treatments will be limited to daylight hours, because of the high supervision needs of the linear move systems and the 8 hours per day restrictions on the government-employed labor force.

Fertility (Waddell, vacant Agronomist, vacant Ag Engineer and other regional scientists). Conventional irrigated tillage plots will follow common grower practice and have all the phosphorus (MAP) and urea nitrogen fertilizer applied uniformly across the plot area and incorporated (ripping, mulching, 2X leveling and bedding) in the fall. In the strip till plots, a starter level of nitrogen (urea) and all needed MAP fertilizers will be banded in the in the fall. Potassium will only be applied when soil tests indicate a deficiency (no build factor). The remaining nitrogen fertilizer will likely be applied as urea ammonium nitrate (UAN 28) with the irrigation water during the season as needed for each experiment. For sugarbeet crops planted on sandy soils (e.g., Nesson Valley site), it may be necessary to side dress nitrogen as well as apply nitrogen though the linear move system to avoid premature nitrogen deficits (determined by bi-weekly plant testing). Micronutrients will be applied, as recommended by the annual soils testing laboratory, either through the sprinkler system or by preplant land applications.

EARC Irrigation Study. The general objective of the MSU EARC research near Sidney, MT is to develop irrigation management and cultural practices that promote water use efficiency, and enhance environmental benefits. The purpose of these experiments is to develop information on the effect of crop sequences, tillage and irrigation methods on crop yield and quality, foliar disease incidence and weed distributions on heavy soils. The subobjective is to develop irrigated farming practices that maintain soil structure, promote soil microbial populations and eliminate the need for expensive post-harvest soil treatments.

This portion of the CRIS is a six-year research plan as shown in **Appendix A** (**Table 3 and Figures A-2 to A-6).** A crop rotation and tillage study was established in the fall of 2003 for the 2004 season under a 245 m long self-propelled linear move irrigation system (ditch feed) owned by MSU. Approximately 4 ha of land are being leased for cropping systems research. The intent is to evaluate modified tillage interactions (convention tillage and strip till) under two irrigation methods (MESA and LEPA, implemented as stated above) (4 reps) four sugarbeet/barley rotations in a stripped block crossover design (56 plots) that changes year by year. The appropriate ANOVA and least significant difference tests will be used to evaluate treatment effects. The plot areas were planted to sugarbeets in 2002 and malting barley in 2003. Each plot area (all malting barley) was harvested individually in 2003 and analyzed for yield, protein, color, kernel size distributions and quality to assess inherent variability across the study site for future use in detrending data sets.

The sugarbeet/barley rotation represents the most common irrigated rotation currently used in the MonDak area. Fall fertilization (N, P, K) and tillage is common due to the cold winters (low N losses), deeply frozen soils and short planting windows in the spring. All rotations in this experiment are intended to maximize net return to the growers (given realistic yield expectations) over the two years. However, we want to minimize tillage as much as possible in ways that are still acceptable to growers using center pivot irrigation. Sugarbeets are on 61 cm rows while barley on 20 cm row spacing. Conventional tillage (CT) and strip till (ST) are the primary tillage treatments for all sugarbeet rotations. CT starts in the fall will consist of two tillage passes with a combination mulcher-ripper equipped with shatter blocks and shatter wings on shanks at a 61 cm spacing, followed by two passes with a roller harrow and two passes with a land plane (normal grower practice). Prior to planting in the spring, an S-tine tillage tool will be used to kill small weeds and create a seedbed suitable for conventional planting equipment. CT barley is tilled with an S-tine tool in the spring after sugarbeets. The ST sugarbeet treatments utilize a custom built coulter and shank tiller (about a 40 cm wide strip) with two fertilizer boxes for side dressing as the primary tillage for sugarbeets in the fall. ST barley is tilled in the spring to mitigate the effects of sugarbeet harvesting activities prior to planting. A conventional grain drill is used for planting the barley.

Standard grower tillage practices (CT) will be used as the control. ST will be used on sugar beets during the preceding fall after barley (some fertilizer will be banded at the same time). Since this will all be under overhead irrigation (linear move), it gives us some options that are not available for furrow irrigated sugar beet rotations including leaving the field flat to reduce runoff and maintain residue between strips. Row crops will be planted on 61 cm spaced beds, and the small grains on a common irrigated 20 cm row spacing. Standard grower practices for fertility (not treatments) and pest control for each crop will be based on MSU recommendations for expected yield goals. Weeds will be controlled by applying approved herbicides, hand removal or cultivation as needed. A row crop cultivator with high residue handling capability will be used in the ST sugarbeets in addition to approved chemicals and/or hand removal.

The amount of water applied (depth) per irrigation will not be varied, but the number of water applications may be adjusted to avoid undue stress or over-applications. Irrigation frequency will be based on a total replacement ET_c of 15.2 mm (0.60 inches) for each crop adjusted for irrigation efficiency. Controllers for precision irrigation will be installed and tested during early spring 2004 (as discussed above). The plots were mapped for EC with the Veris™ 3100 in the spring 2003 on a 10 m spacing, soil sampled in fall 2003 in 30 cm increments to 120 cm (where possible) at two locations in each plot, and analyzed to obtain baseline data to characterize the soil as previously described. In addition, data will be collected (2X/plot) to characterize SOM, POM, water stable aggregates (WSA), total microbial biomass, and selected soil microbial populations in Spring 2004. Soils will also be sampled in the top 30 cm, biweekly, during the growing season to monitor available nitrate concentrations. Subsequent annual soil samples will focus on N, P, K and some micronutrients at the 0-15 and16-30 cm depths, and only N at the 30-61 cm and 61-122 cm depths. After the 2003 barley harvest, a base fertilizer level (partial N and P requirements for annual sugarbeet production) was applied and incorporated. Additional N will be added during the growing season by side dressing or through the irrigation system.

Nesson Valley Irrigation Study. The NDSU farm in the Nesson Valley is located about 120 km from NPARL on the north side of the Missouri River. A 366 m long self-propelled Valley linear move (hose drag) irrigation system, has been erected at the site on a 16 ha block. The water supply system will be installed in spring 2004. Uncertainties associated with the completion of the water delivery system in 2004 have postponed the anticipated research start date to the spring 2005. Controls for precision irrigation (MESA) will be installed and tested in the summer of 2004.

The goal of this irrigation research is to improve agricultural water use efficiency for self-propelled irrigation systems in the NGP. The general objective of this experiment is to develop information on the relative effect of crop sequences, tillage and irrigation frequency on water use for various crops, yields and crop quality, foliar disease incidence and weed distributions on sandy soils. We will implement six crop sequences **(Table 4: Appendix A)** with four replications in stripped block design (48 plots), and the appropriate ANOVA and least significant difference tests will be used to evaluate treatment effects. This represents some typical grower cropping practices for irrigated potato/sugar beet/barley crop management in the NGP. The potato and sugarbeet row spacing will be 61 cm and irrigated small grains will be planted in the commonly used row spacing of 20 cm for these crops. Fertility and pesticide use are not treatments and will be based on NDSU recommendations.

The soils have not been previously irrigated (currently in dryland alfalfa and grass hay production) and this is a great opportunity to track changes in the soil microbiology and soil structure as irrigated farm management is imposed. Thus, an additional 15 m wide X 240 m long strip of precision irrigated and dryland grass-alfalfa hay (current dryland hay crop to be maintained, irrigated and harvested) will also be established (8 plots, RCB, 4 reps) adjacent to the crop sequence plots to better track soil quality changes (e.g., soil microbe populations & distributions and enzymes [Caesar-TonThat].) during the transition from dryland to irrigated no-till practices, over the 4 years. The crop sequence study will also be sampled as part of the transition effects study.

Irrigations in the crop sequence study will apply the full soil water replacement amount when the calculated cumulative ET_c requirements are 15.2 mm or 30.4 mm at an assumed 80% application efficiency (applying the same total amount of water over the season). Standard grower practices will be used as much as possible. Since the sandy soils are subject to severe wind erosion when cover is removed (especially in late winter and spring), we will try to conserve as much surface residues across all plots as possible in winter.

Soil sampling was conducted in 2002 on the grass-alfalfa hay fields (60m x 60m grid) and analyzed for chemical and physical characteristics as previously described to 120 cm depth. The area was also mapped for EC variations in 2003 at 10 m spacing. The 16 ha study area will be more intensively sampled with two sites per plot (20m by 20 m grid) with DGPS coordinates (2004). In addition, data will be collected to characterize SOM, POM, WSA, total microbial biomass, and selected soil microbial populations in 2004 for each plot as a baseline to help quantify soil quality changes during the transition from dryland to irrigated production at the site.

Ecological, Physical and Physiological Relationships. Many of the procedures and methods for ecology, plant pathology and soil quality research will be the same for both the primary dryland and irrigated research sites discussed in this proposal. These are presented below.

Plant Pathology (Lartey, Sainju, vacant Agronomist, Evans): Attaining sustainable yields under diverse irrigation and dryland crop production systems strongly depend on understanding relationships between the various cropping strategies and disease incidence. Molecular techniques such as PCR, pulsed field gel electrophoresis, cloning and sequencing will be utilized to elucidate the biology of host pathogen interactions as basis for developing an efficient biological control systems against pathogens that minimize pesticide usage. In addition, we will continue working on completing the genomic sequencing of *C. beticola,* and possibly relevant FHB causing organisms to help provide new insights on host-pathogen interactions.

A successful biological control program depends on isolating and identifying the appropriate antagonists that can overcome any toxins produced by the organisms. Cercosporin, a toxin produced by *Cercospora* spp. is toxic to a wide range of organisms including other fungi, bacteria, plant and animals. The toxin is likely a self-defense mechanism developed by the pathogen to protect it against a potential antagonist as well as a means to breakdown host cell walls for food. Initial biological control efforts will be based on the identification, evaluation and application of known natural antagonists (e.g. *Trichoderma harzianum*, *T. aureoviride* and *Laetisaria arvalis*) and the natural products they produce (e.g. laccase from *L. arvalis*) to combat diseases such as CLS and FHB. Laccase produced by *L. arvalis* has been shown to degrade cercosporin (Caesar-TonThat *et al*, unpublished). Studies indicate that the cercosporin is crucial for the pathogen (*C. beticola*) to obtain nutrients from host plants (Daub and Briggs, 1983; Caesar-TonThat *et al*, unpublished). Laccase will be further evaluated for its ability to breakdown cercosporin and prevent *C. beticola* from obtaining food from host plants. FHB toxins will also be evaluated for sensitivity to laccase as a potential biocontrol. Biochemical, molecular and microscopy techniques can be applied to resolve relationship between plant host/pathogen/antagonist as a means of optimizing biocontrol mechanisms of the biological agent. For example, microscopic techniques could be used to resolve the mode of action of potential biological control agent against the pathogen. Real time PCR can be used to determine which organisms are present and to indicate the microbial diversity. Biochemical techniques could also be applied to identify and study the mode of action of metabolites from the biocontrol agents on the suppression of the pathogen.

In addition, other potential antagonists (e.g., for foliar biocontrol: Bacillus sp and Streptomyces sp; and for FHB: L. arvalis and Trichoderma sp.) , capable of suppressing *CLS and FHB* will be tested as soil and/or plant applied fungal inhibitors in growth chamber and greenhouse studies. Replicated treatments (4 to 6x) will include 1) the application of antagonists to *C. beticola and Fusarium spp* inoculated plants; 2) inoculated plants without antagonist treatment; 3) antagonist treatments on uninfected plants; and, 4) untreated controls. Appropriate standard ANOVA tests will be used to evaluate the antagonist's biocontrol efficacy and differences among treatments.

Soil Aggregation and Biochemical Properties (Caesar-TonThat, Sainju). Biological and biochemical markers for soil quality and productivity will be determined on dry and/or WSA and whole-soil collected from dryland and irrigated plots treated with tillage, cropping sequences and cultural practices. Aggregates will be separated using dry (Mendes et al., 1999; Schutter and Dick, 2002) and wet sieving (Elliott, 1986) to represent field conditions. Mean-weight diameter of aggregates will be measured according to Kemper and Rosenau (1986). Microbial communities, enzymatic activities, and C and N pools will be correlated in the whole-soil and in aggregates. Analysis of comparisons among land management treatments will be done using SAS PROC MIXED.

An enzyme-linked immunosorbent assay (ELISA) developed at NPARL-Sidney, will be used to detect and quantify specific soil aggregating basidiomycetes (Caesar-TonThat et al., 2001). Soil samples collected from each treatment area will be incubated at room temperature. The quantity of basidiomycetes will be expressed in mg/g soil. A colormetric procedure (690 nm) based on m-hydroxydiphenyl (Blumenkrantz and Asboe-Hansen 1973; Van den Hoogen et al. 1998) has been modified to quantify uronic acids (resulting from sugars reduced by bacterial and fungal activity) in WSA. This test will be used to evaluate the effect of the various ICPS on the content of uronic acids in the aggregates and to develop a standard curve relating galacturonic acid and soil aggregation stability as a measure of soil quality. All samples will be processed in triplicate and the quantity of uronic acids will be expressed in µg/g soil. Other soil parameters being evaluated include; soil OM degradation caused by the enzymes invertase and/or xylanase (Schinner and Von Mersi, 1990) expressed as µg glucose $g^{-1}h^{-1}$.

The C and N pools determined in the whole-soil and aggregates will be organic C and N, particulate organic C and N (POC and PON), potential C and N mineralization (PCM and PNM), microbial biomass C and N (MBC and MBN), and inorganic N (NH_4 and NO_3). Organic C and total N will be determined by C and N analyzer, inorganic N by autoanalyzer, POC and PON by the procedures used by Cambardella and Eliott (1992) and Beare et al. (1994), MBC by Jenkinson and Powlson (1976), MBN by Voroney and Paul (1984), PCM by Zibilske (1994), and PNM by Hart et al. (1994). Soil quality and productivity and C and N sequestrations in the soil as influenced by tillage, cropping sequence, and cultural practices will be determined by measuring OM dynamics, microbial activities, and N mineralization in the whole-soil and aggregates. These activities will be integrated into the ARS National Soil Management Assessment Program

Contingencies: In the event of abnormally dry spring soil conditions, minimal supplemental (< average monthly precipitation) sprinkler irrigations will be used to ensure crop emergence in dryland (small plots) experiments. Disease and weed biocontrol systems will not be limited to a single antagonist, but to a wide range of organisms and physiological responses (e.g., various Bacillus, Streptomyces, Trichoderma spp.) Implementation problems with precision irrigation control and water supply systems may delay the start of NDSU plot work by one year. Interpretation of field and remotely sensed data may require limited projects examining temperature, soil water, weeds, disease, fertility and other factors on yields and quality. B-glucosidase activity (a hydrolytic catalyst) measurements will be an alternative to invertase and xylanase activity in the event these tests prove to be unreliable. Failure of automated and other field instrumentation caused by weather, animals or vandalism may necessitate new equipment purchases, repairs, and/or supplemental manual measurements. Erratic, unclear or unforeseen results may necessitate additional small field, lab and/or greenhouse experiments to specifically separate effects of various factors leading to possible modifications of the primary experiments.

Objective 2: *To quantify environmental benefits from improved soil and water management, diverse crop rotations, reduced tillage, and selected combinations of cultural practices on plant, soil and water resources.* ***Hypothesis 2a:*** Increased crop diversity and intensity, reduced tillage, and precision applications of nutrients, pesticides and water will maintain, or improve, yield and crop quality, decrease nutrient and water inputs and improve water quality (e.g. decrease nitrate leaching to groundwater, sedimentation levels, pesticide levels); ***2a-1:*** More frequent, low volume, variable rate irrigations during the growing season can improve productivity and reduce nitrate leaching; ***2a-2:*** A synergistic mix of remote sensing and on-the-go within field sensing of soil and plant status can decrease water and energy use through better timing of inputs for water, nutrient and pest management; ***2a-3:*** Biologically-based control of pathogens and weeds will reduce pesticide inputs and enhance surface and groundwater water quality of irrigated and dryland systems; ***2a-4:*** Increased organic matter concentrations in the soil with conservation tillage and increased cropping intensity will increase nutrient mineralization while increasing carbon storage*;* ***Hypothesis 2b:*** Knowledge of interrelationships between crop sequences, tillage, and irrigation frequency on water use, production and crop quality will assist in development of advanced nutrient and water management strategies and technologies to improve environmental sustainability; ***2b-1:*** Water management strategies and technologies can be developed that reduce leaching of agrochemicals and improve the ecological viability of irrigation enterprises in the NGP; ***2b-2:*** Precision nutrient management strategies and technologies can be developed that match plant needs while minimizing total applications and enhancing crop quality goals; ***Hypothesis 2c:*** ICPSs can be developed that improve soil quality (e.g. soil aggregation, nutrient cycling) while reducing specific pathogen and weed incidence; ***2c-1:*** Minimum-till, diverse ICPS strategies can increase soil aggregation and improve soil structure; ***2c-2***: Ecological, diverse rotations can be managed to reduce pathogen and weed incidence in irrigated and dryland systems. ***Hypothesis 2d*: A reduction in herbicide use combined with enhanced weed control can be realized with a cultural, ecological systems approach to weed management; ***2d-1:*** Management differences under the selected ICPS will influence the abundance and diversity of weeds and plant pathogens and the functional interrelationships between the weeds, plant pathogens and their antagonists.

Experimental Design: Within the experimental framework develop in Objective 1, additional efforts will be directed towards assessing and quantifying the environmental impacts of cultural practices and improved water and nutrient management on soil and water quality, runoff, leachate, and weed/disease ecology. Specifically, the effects of soil disturbance (under overhead irrigation) will be examined to determine the impact of various ICPS on weed populations, disease incidence, soil structure, crop yield, soil quality, agrochemical leaching, and runoff (water quality). Nutrient and soil water management alternatives (e.g. precision agriculture) will be evaluated using a combination of existing models (e.g., 2DSOIL [Timlin] & NLEAP [Ahuja, Follett]), laboratory and field measurements. The interrelationships (ecological-physical-physiological) between different cropping sequences, tillage and soil water management impacts on soil and water quality will be evaluated using small plot and field scale research.

Environmental Monitoring (Evans, vacant Ag Engineer, Waddell, vacant Agronomistt). Depending on variations in crop rotation and C:N ratios of residues, soil may act either as a source or sink for available nitrogen. The availability of N over the growing season from typical and alternative dryland and irrigated rotations region will be monitored to assess seasonal and long-term N mineralization and fertilization effects on soil N, plant growth and yield. Soil nutrient cores will be taken in and between rows for sugarbeets and potatoes and randomly for small grain plots on the large dryland and irrigated rotations with two replications per plot. *In-situ* soil solution nitrate concentrations will be measured/monitored using resin extraction techniques (Skogley and Dobermann, 1996) in the root zone at 5 and 30 cm along with evaluation of water status (using neutron probe every two weeks to a depth of 150 cm in 30 cm increments beginning at 15 cm depth, and continuous Watermark® moisture block readings using dataloggers) to evaluate water and N movement. Resin-based analysis will be used in both time sequence and periodic replacement studies to determine nitrate mineralization/immobilization throughout the season. Above ground biomass and soil cores to 150 cm will be taken at preplant, twice during the growing season, and at harvest. These data will be compared with control plots (no applied nitrogen) to determine N budgets and the relative impact of N fertilization on N mineralization in the different rotations.

Soil N mineralization potential in the NGP will be analyzed with a quick procedure identified by Picone et al., 2002 and compared with seasonal incubation studies in the lab. The potential N mineralization will be compared to actual mineralization rates, water contents, and temperatures occurring in the field to determine the long-term impacts of tillage and crop rotation. The ultimate goal is to accurately predict soil N production, immobilization and loss (considering previous crop history, cultural practices, climate fluctuations and soil conditions) using models like 2DSOIL (with D. Timlin) or NLEAP (with L. Ahuja/R. Follett). These models will also be used to indicate areas where leaching will likely occur under various scenarios. Biotic assimilation and release of nitrates will be investigated with Drs. Caesar-TonThat and Sainju using ELISA and HPLC techniques.

Soil and Plant Status Sensor (Evans, vacant Ag Engineer, vacant Agronomist*).* As part of the evaluation of environmental impacts, procedures will be developed and tested for wireless, sensor-based on-the-go precision irrigation scheduling using automated on-site micrometeorologic and soil water sensors plus other remotely sensed data (e.g., nitrogen, IR t, etc) at the EARC and Nesson Valley. Automated radio-linked microclimate/soil water stations will be distributed across the field (minimum of 4 per field) based on EC measurement maps (Veris™ 3100), yield maps and soil sampling to ensure coverage the most critical areas. The goal is to ensure that field areas with different soil water holding capacities, fertility, and crop production potential are monitored for various environmental and soil conditions (minimum, in-canopy air temperature, relative humidity, precipitation, water application, soil temperatures, soil water content at 30 and 70 cm, and possibly plant canopy temperature). The accuracy of the soil water sensors will be determined using field soil samples and a neutron probe (field calibrated, CPN 503 DR). Remotely collected data will be transmitted, via spread spectrum radios back to receivers mounted on the irrigation system towers and relayed to a base computer for analysis and possible real-time adjustments of applied water. Other sensors (e.g., digital video cameras, hyperspectral radiometer and imagers) will also be used to obtain additional site-specific field information. The long-term goal of this research is to integrate field based information networks with aerial remote sensing, existing plant and pest models, and other technologies to provide data products that can improve the timeliness and precision of field augmentations through the irrigation system (e.g., leading to “on-the-go” irrigation scheduling). A post-doctorate person will be recruited to handle these aspects in spring 2005.

Sensor evaluations will focus on the use of ground-based sensors supported by periodic aerial hyperspectral imagery (in collaboration with G. Anderson) to identify and quantify crop variables for real-time or within season management decisions. We don’t believe that only one sensor or remote sensing system can provide the range of information needed to make real time decisions. The objective of this aspect of the research will be to evaluate different remote sensing tools to determine which combinations provide the best information for different irrigated and dryland crops within the selected rotations and locations. The approach will use a series of aerial images and ground based sensor readings (e.g., field-calibrated soil water, microclimate, infrared temperature, band specific reflectometers, Veris EC, etc) to compare with various key crop variables quantified in the field and laboratory. Ground-based sensors used in collaboration with other ARS locations to measure plant nitrogen status (e.g., “Green Seeker” [Lincoln, NE], boom-mounted sensors [Ft Collins], IR thermocouples [Phoenix, Lubbock]) will also be used. This aspect of the research augments ongoing research efforts with similar foci and provides for a sharing of research knowledge and instrumentation. It is hoped that these combined efforts will help identify inefficacies in nitrogen and water application and ultimately provide some basis for managing spatial variability.

Key crop variables that will be measured throughout the growing season include; above ground and below ground biomass, plant nitrogen status, crop yield, and crop quality measurements. The measurement of yield is usually straight forward, but crop quality varies with the crop being studied and is often influenced by crop variety and weather. Most of this work will be done on irrigated sugarbeets/potatoes and the field’s rotational subsequent crops (e.g., typically wheat, corn, barley). Laboratory measurements will be obtained from the biomass samples and include above ground plant nitrogen/carbon concentrations and below ground root nitrate levels and sucrose content (for sugarbeets) and seed protein content (for small grains). Aerial imagery will be acquired (to the extent possible) concomitant with field sampling to develop functional relationships between key variables and the imagery. Imagery will also be collected over specific grower fields to assist in evaluating the results of various practices and strategies. These data will also assist in evaluations of water application technologies to verify nutrient and water distribution patterns, stress detection, soil color mapping, locating potential field management zones, mapping of weed types and distributions for precision weed control, and to assist pest scientists in determining the extent and spatial dynamics of crop pests (e.g., *C. beticola)*, plus other needs that emerge during this project.

Various sensors will be utilized on small plot studies at the EARC and Nesson Valley sites where other scientists are simultaneously collecting detailed plant, climate and soils data (as described above). Plant samples (biomass, nutrient status, yields [Mg ha^{-1}], and quality [e.g., % sugar and brie nitrates for sugarbeets, % protein for small grains]) will be compared with data provided by the "green-seeker," hand-held hyperspectral radiometer, and aerial hyperspectral imager. Samples will be obtained concomitant with ground based and aerial based remote data acquisition three to four times throughout the growing season. The resulting aerial and ground-based data will be compared with laboratory results of nutrients, crop quality and crop quantity using multivariate regression models. These analyses will help evaluate the ability of the remotely sensed data to reliably predict measured crop variables both spatially and temporally. Geostatistical approaches will be used to help evaluate the ability of remotely sensed data to predict different yield levels and crop quality parameters (spatially and temporally) in uniformly managed fields.

<u>*Weed ecology and crop sequencing experiments* (Lenssen, Sainju, Caesar-TonThat and other regional scientists).</u> Weed ecology research will use a systems approach that includes cultural practices and herbicides to reduce weed seed bank and weed competition. This work will be coordinated by one of our new scientists and methods will be developed as needed to achieve this objective. Data will be collected on weed species composition and densities at key periods of crop and weed growth by field measurements from 400 plots in crop sequencing and ecological crop management experiments previously described at the Rasmussen, Culbertson, Sidney and Nesson Valley research sites. Weed species densities in both dryland and irrigated studies will be determined in ten 929 cm^2 circular quadrats per plot about 3-4 weeks after crop emergence, after any herbicide application and just prior to crop harvest. Clipping, separation, and drying will be used to determine weed species densities, biomass, and seed production. Data will be analyzed with SAS PROC GLM, PROC MIXED, and multivariate models. Regression analyses will help determine relationships and predictive functions between and among weed parameters and soil quality.

One way to assess the effect of cropping systems on weed production is to evaluate the weed seedbank. Relatively little research has been conducted on weed seed banks, as compared to post-emergent weeds research. Spatial variability and the time consuming work of speciation and enumeration limit the number of samples that can be adequately processed. The weed seedbank will be evaluated at study initiation, mid-point, and completion of fieldwork for all 350 plots within long-term crop sequencing studies previously described for dryland and irrigated sites. Each plot will be sampled 25 times with a 2.5 cm diameter soil core to 10 cm depth. Soil cores will be combined within each plot. Seeds will be extracted from each composite soil sample with an elutriator, separated by density gradient centrifugation, and identified to species for important weed species, including kochia, wild oat, green foxtail, and redroot pigweed with the aid of a dissecting microscope. Data will be analyzed as described in the previous paragraph.

Weed seeds disappear over time. Few studies have been conducted on the factors responsible for weed seed disappearance following seed rain. A related issue is the role un-germinated seeds play in meeting the food requirements of various arthropods, microbes and small animals. Field and laboratory studies will be conducted with MSU entomologists (Blodgett & O'Neill) to document potential levels of biological control of specific weed seeds (green foxtail, kochia, wild oat) by carabid ground beetles (*Coleoptera: Carabidae*). These studies will determine the consumption potential of these predominant insect species (commonly found after crop harvest) on weed seeds in NGP dryland wheat and irrigated sugarbeet fields. Six replicated laboratory trials with the predominantly encountered pre- and post-harvest carabid species will measure seed predation in choice and no-choice trials with kochia, redroot pigweed, wild oat, and green foxtail seed. These trials will determine quantity(s) of weed seeds consumed, thus relating seed predation to potential and measured changes in field weed seed bank studies. Laboratory trials will be conducted in

Sidney and Bozeman. Field activity estimations of carabids will be done by pitfall trapping 24 plots, three traps per plot, in conventional and diverse rotations. Insect traps will be collected for one of every third week from harvest through October. Data will be analyzed with SAS PROC GLM, PROC REPEAT, and various multivariate regression models.

Plant Pathology (Lartey, Caesar-TonThat, Lenssen). We will survey and appraise weeds and non-target crops in the area as potential secondary hosts of *C. beticola* and *Fusarium spp*. Real time PCR (based on Lartey et al., 2003) will be used to rapidly detect the pathogens. Pathogen specific primers will used to amplify and detect target segments of the pathogen genomic DNA from plant tissue extracts from infected crops, residues and secondary hosts. Confirmation of the presence of the pathogen in the plant tissue is based on comparisons of the amplified products of the pathogen from suspected tissues with pure cultures of the pathogen. If in doubt, the products will be sequenced and compared using appropriate software, such as Vector NTI. Controls will consist of either pure cultures of the pathogen or purified DNA extracts. Disease severity ratings will be based on percentage of lesions on sampled leaves in relation to lesion free area on sampled leaves using WinDIAS (Delta-T Devices, Cambridge, UK). Data concerning disease severity of sampled fields will be analyzed by ANOVA, and mean field treatment differences will be compared using Tukey's Test. Newly identified hosts will be subjected to Koch's postulate to confirm that they are hosts of the pathogen. Inoculum potential will be based on detectable amounts of pathogen propagules found in infected plant residues and secondary hosts. Pathogen specific antibodies will be used to detect and quantify the various pathogens in the soil using ELISA techniques.

Contingencies: Hyperspectral data will be obtained from both the CASI II and ground radiometers; and, in the event one fails the other will still supply many critical data requirements. Failure of automated and other field instrumentation caused by weather, animals or vandalism may necessitate new equipment purchases, repairs, and/or increased use of supplemental manual measurements. Unexpected results may necessitate additional plot, laboratory, and/or greenhouse experiments to specifically separate effects of various factors leading to possible modification of the primary experiments.

Objective 3: *To extend research results and increase adoption rates by testing promising plot research outcomes on growers' fields, and by using feedback from both plot and field research scales to calibrate existing models for uses in combination with GIS and other valid management tools.* ***Hypothesis 3a:*** Knowledge obtained from research conducted in Objectives 1 and 2, along with research conducted in cooperation with other ARS researchers and university collaborators, can be used to reliably assess the potential benefits and costs of managing field variability, improve on-farm irrigation system performance, and optimize water and nutrient application rates; ***Hypothesis 3b:*** Replicated field-scale experiments of improved ICPS and large-scale integrated disease and weed management trials, conducted over broad areas on representative soil types with grower, extension and industry involvement, will highlight the advantages of each system and facilitate adoption of improved farming practices and technologies by the agricultural community; ***3b-1*** Demonstrating remote sensing and real time on-the-go within field based sensing of soil and plant status will provide within session information to growers for more timely crop management. ***Hypothesis 3c:*** Field-scale trials comparing diverse cropping with reduced tillage and ecological crop management will be established under this CRIS, with the ultimate objective (7-10) years) of demonstratively proving those systems are more economically stable than conventional small grains production. ***Hypothesis 3d:*** Evaluation of multiple remote sensing tools, at multiple locations and for different crops, will demonstrate the effectiveness and ability of each tool to improve within season nitrogen management. ***Hypothesis 3e:*** New techniques and analytical procedures can be developed that are user-friendly and improve the grower's ability to interpret spatial data, which is currently very time-consuming and technologically challenging. ***Hypothesis 3f:*** Improvements to management technologies and procedures will increase the rate of site-specific field management adoption over broad geographic areas.

Experimental Design: It is difficult to design a technology transfer program before research results become apparent, consequently the hypothesis for this objective are more like goals for irrigated and dryland systems. We know that scientifically sound agricultural research requires a high level of control over the variables influencing treatment effects, and for this reason much of the research must be done at a subfield (plot) level. However, a fundamental paradigm is that as research is extended to larger scales, additional research is required at each level to account for the increased complexity of the farming systems and to validate the utility of the newly developed practices from field to field and region to region. This step is viewed as technology transfer, however, it also is essential research needed to define the advantages and drawbacks of each effort at various scales and, when possible, identify and correct impediments to the procedures that may limit adoption.

The goal of this technology transfer objective is to: 1) provide collaborators with the data needed to calibrate existing models (e.g., GPFARM http://infosys.ars.usda.gov/gpfarm.htm , CPED: http://www.wmuinfo.usda.gov/) for irrigated and dryland conditions, and 2) allow for the development of comprehensive datasets (e.g., ag weather networks, remote sensing, EC and yield maps) needed by ASRU scientists to develop GIS and other analytical tools to improve our understanding of the agro-ecosystems. We will work with our cooperators and collaborators to determine the best process/mechanisms to identify, develop, design, and jointly interpret studies to capitalize on the linkages across disciplines and field sites.

In order to identify instrumentation locations in grower fields, GIS databases will be used to overlay layers such as: topography, water holding capacity, irrigation application depth maps, remotely sensed canopy cover maps, EC maps, soil nutrient parameters with depth, soil texture and other spatially distributed factors. Yields will be mapped whenever possible. Point data, yield monitoring and aerial remote sensing results will be used to help formulate guidelines for adjusting the amounts of water and nitrogen applied by center pivot and linear move irrigation systems for subsequent growing seasons, if necessary. Classical as well as non-traditional geostatistical methods will be used to determine areas where sampling efforts need to be increased in order to ensure sufficient sample sizes of plant and soil measurements, interpolate data at unsampled locations, and assess the variability of field soil and plant sampling.

Locally calibrated models (i.e., Ahuja: GPFARM) will be used to evaluate each dryland and irrigated ICPS. The models will be used to explore implications of various management strategies, increase grower access to relevant, regional economic and management information, and provide feedback to the researchers concerning potential modifications. We will be working closely with the model developers to verify model projections for NGP conditions. Quantification of management impacts on soil biota and enzymatic activities will be a valuable tool for assessing soil quality and provide feedback to growers, researchers, action agencies and the National Soil Management Assessment Framework on appropriate technologies and strategies for improved crop management.

Aerial remote sensing (in collaboration with G. Anderson) will also be used to help identify and map weed occurrence in various rotational components. Ground-truth of weed infestations and densities will be mapped utilizing GPS to mark sampling locations. Soil sampling for weed seed soil banks will be collected in key locations within each grower field and research plot at the start of the season to establish baselines and at the end of the trial for the net effect. Data will include densities of viable weed seeds by species and depth of burial, thereby allowing us to determine the long-term effectiveness of tested management strategies on decreasing future infestation levels. Regression analyses, including rectangular hyperbolic models and geostatistical analyses of spatial data will be used to determine the severity of weed interference on crop yield and quality.

Precision irrigation controls and various sensor systems will be installed on at least one collaborator's center pivot system to evaluate large-scale precision water management alternatives and agrochemical applications. Meteorology stations and microclimate stations, similar to those located at research sites will be placed in cooperators' fields and other strategic locations in the area to help extrapolate results to other sites. Various methods will be assessed (catch cans, aerial remote sensing maps, etc.) to determine water infiltration variability across fields (statistical & analytical). This information will improve the management of center pivot irrigation systems. Catch can data collection and analyses (for each field) will follow the procedures and guidelines in ASAE Standard S396.1 (ASAE, 2002). This will be accomplished in conjunction with aerial remote sensing and a hydraulics-based center-pivot irrigation model (e.g., D. Heermann: CPED) to estimate water application depths and uniformity across the entire field. Whole field water distribution maps will be generated by this model and placed as a data layer in the GIS database. These data layers will be used in various models and graphical techniques utilizing point sensor, soils and plant sample data, remotely sensed images and topography, EC, yield, weed and disease maps for the same fields with GIS to evaluate technologies and practices, analyze management and economic impacts and improve grower acceptance and adoption.

Several informal collaborative research arrangements have been established to study the effects of various ICPS on soil aggregates, soil aggregating basidiomycete fungi, uronic acids, and soil enzymes on both croplands and rangelands to verify the universality of these concepts.

Following growth chamber and greenhouse evaluation, field trials will be carried out to test the efficacy of the identified biological agents to suppress CLS of sugar beet and FHB of barley and wheat. Various formulations involving fungal propagules such as spores, sclerotia and mycelial preparation will be evaluated for shelf life and efficacy for control of *C. beticola* and *Fusarium* species at the research fields in collaboration with NDSU, Fargo and MSU, Bozeman.

Contingencies: If field scale collections are not possible, the plot studies will still provide valuable knowledge and ensure continuity of this effort, and provide valuable input to models. If GPFARM or other models perform poorly for NGP conditions, modifications by the developing Units may be made or other models considered. Conducting research at multiple locations limits the adverse impacts of localized weather patterns (e.g., hail), thus allowing the project to continue at the remaining sites. We will be using multiple levels of instrumentation for varied data collection activities, and if any one instrument fails the study will not be compromised. The implementation of precision irrigation control technologies may be delayed if a suitable collaborator cannot be found, but control information from the plot studies will still provide needed information to extent the results to on-farm conditions. Unexpected results may necessitate additional small field, lab and/or greenhouse experiments to specifically separate effects of various factors leading to possible modification of the primary experiments.

NATIONAL AND INTERNATIONAL COLLABORATIONS

The success of certain aspects of the ASRU projects depends on the results, models, and data collected at other locations. Climatic, soil and water resource differences are important factors that must be considered for developing and adopting new cropping technologies. Our collaboration with Montana State (Bergman and Flynn) and North Dakota State Universities (Bergman, Staricka, Hill and Steele) provides considerable additional local expertise and emphasizes the need for effective communication, careful planning and coordination. Entomological support will be provided by scientists in the Pest Management Research Unit at Sidney as well as through MSU (Blodgett) and other collaborations. C. Hill, an alternative crops specialist/ag economist with NDSU will assist in economic analyses. G. Anderson is collaborating on remote sensing efforts. Our plan is to continue collaboration with current local farming partners, industry, and universities and to expand collaboration with other ARS locations with similar interests and complementary research.

We are quite familiar with other projects investigating irrigation system automation, spatially variable applications technology and sensor development at Ft. Collins, CO; Florence, SC; Sidney, MT, Lubbock, TX, Columbia, MO, Lincoln, NE, and Phoenix, AZ, and we have established collaborative efforts with the scientists from each of these locations. This research is part of the National effort to develop and test various precision agriculture approaches. An ARS meeting was held on this topic in early 2003 in Kansas City, MO to encourage collaborative research. A follow up ARS meeting was held in San Diego in November 2003 to further define roles and expectations with respect to precision irrigation. Cooperative precision agriculture work is planned with USDA-ARS laboratories at Fort Collins, CO; Lincoln, NE; and Columbia MO. We will install and test precision irrigation controls and sensor technologies for managing precision water applications and for measurement of the spatial variability of crop water and nutrient status. Each location is investigating a particular set of techniques that are, in whole, complementary rather than duplicative.

Collaboration with other locations will involve field testing their sensors in the NGP and collecting data necessary for appropriate computer models at each location. Our development of a database of weather, soil water content and temperature, crop/weed development and agronomic data will allow us to cooperate fully with ARS-GPSRU, Ft. Collins in testing and validation of the GPFARM model and NLEAP for NGP conditions. We will also be working with D. Timlin in Beltsville regarding use of the 2DSOILS model on water and nutrient fluxes. Results of sprinkler uniformity testing and precision irrigation testing will be used in combination the CPED model developed by the ARS-WMRU, Ft. Collins to evaluate precision water management scenarios and practices. We will be open to cooperative efforts with other modeling groups within ARS as the availability of our databases become more widely known and as those opportunities arise.

Data sets from a number of locations allow the development and use of general farm management software dealing with a range of conditions and providing guidance concerning the benefits and limitations of various approaches. For example, Lubbock, TX, Florence, SC, Aberdeen, ID, Prosser, WA and Sidney, MT are investigating potential benefits of variable water application to compensate for translocation within and off the field due to topography or soil conditions. Efforts at Fort Collins, CO are focused on more uniform application and managing to minimize field translocation of water. Mutual cooperation will focus on the applicability of various techniques for managing translocation and the value of variable rate water application. Florence, SC and Aberdeen, ID are interested in variable application of chemicals through the irrigation system, as opposed to a mounting a separate commercial system on the self-propelled irrigation system. The latter type of system is currently being evaluated and tested at Fort Collins, CO. We are also collaborating with Fran Pierce at Washington State University on various aspects of precision agriculture research.

Remote sensing techniques (with G. Anderson) will be used to provide additional insights on plots and improve interpretation of treatment effects on grower fields. Remote sensing research at Weslaco, TX, Sidney MT, Fort Collins, CO, Lincoln NE, Bushland, TX and Phoenix, AZ are using different platforms for data collection (e.g. ground, aerial) and have complementary equipment. Developing common data sets from each location will enable comparisons to assess which soil and crop conditions are most and least favorable for various technologies. Different water and vegetative indices are being evaluated and mutual test plans developed. Close coordination of research efforts will help researchers determine the universality of tools and approaches and help determine what tools should be included in a comprehensive regional assessment package.

Brookings, SD, Ft. Collins, CO, Akron, CO and Sidney, MT are evaluating the impact of different cropping systems and cultural practices on weed viability, soil weed seedbanks, and delaying herbicide resistance. Ft Collins, CO, Prosser, WA and Florence, SC are also evaluating variability of the weed populations or variability of soil characteristics affecting herbicide efficacy. Cooperation will focus on developing common approaches for mapping and prescribing management with appropriate modifications for regional differences in weed ecology and production systems.

National collaboration is needed to answer broader cropping systems questions. In addition to the study sites in MT and ND (cited in this project plan), collaborations with other scientists have been developed to cover a broad range of management strategies, cropping systems, soil types, and climates. These are: 1) Soils from 3 dryland farmers growing wheat and pea (Dale Farebee, NRCS, Beach, ND); 2) Soils from field plots growing tomato under different tillage management maintained by Dr. E. Rosskopf, ARS, Fort Pierce, FL; 3) Soils from field plots growing corn and soybean under different management strategies with Dr. R. J. Kremer, ARS, Columbia MO; and, 4) Soils from cattle grazed or no-grazed rangeland in northern Montana with the BLM, Billings, MT.

Collaborators: G Anderson, ARS-Sidney; J Hanson, J Krupinsky & K Nichols, ARS, Mandan; M Vigil, ARS, Akron; D Heermann, L Ahuja, R. Follett, G. Buchleiter, H. Farahani and W Bausch, ARS, Ft Collins; T Howell & S Evett, ARS, Bushland; D Wanjura, ARS, Lubbock; J Sadler & R Kramer, ARS, Columbia; R Anderson, ARS, Brookings; J Schepers, ARS, Lincoln; J Weiland & W Shelver, ARS, Fargo; S Wuest, ARS, Pendleton; S Wright, ARS, Beltsville; D. Timlin, ARS, Beltsville; D. Karlan, ARS, Ames; P Pinter, ARS, Phoenix; J Staricka, NDSU-Williston; J Bergman, NDSU & MSU; J. Eckoff, MSU-Sidney, S. Blodgett, MSU-Bozeman, K. O'Neill, MSU-Bozeman, C. Flynn, MSU-Sidney, C. Hill, NDSU-Williston, D. Steele, NDSU-Fargo, F Pierce, WSU-Prosser; S Ghoshroy, NMSU-Las Cruces; B. Jacobsen, MSU-Bozeman; D. Karlan; J.A. Verreet, Christian-Albrechts Univ., Kiel, Germany; R Pezet and O Viret, Federal Agro, Nyon, Switzerland; and selected MT and ND producers. Some letters of collaborative support are included in **Appendix C**.

PHYSICAL AND HUMAN RESOURCES

The Northern Plains Agricultural Research Laboratory is located on 10 acres of federal government land near the town of Sidney, Montana. The ASRU currently has/will have eight scientists and ten highly skilled, full time technicians. Two technicians are largely responsible for fieldwork in the dryland and irrigated research (both also collect data, analyses and supervise student aides.) We also hire eight to ten temporary student helpers in the summer and during school breaks. The unit manages 140 acres of leased dryland and 48 acres of leased irrigated lands at this time. The main office, laboratories, and greenhouses (federally owned) are composed of 46,000 ft^2 of state-of-the-art air-conditioned laboratories, offices, support work areas, and 2000 sq ft of greenhouse (plus an additional 4000 sq ft of state-of-the-art greenhouse space to be added in next two years). Laboratory equipment is <u>excellent</u> for the purposes of this research and fairly new. Features include: *soil and water chemistry, microbiology, and plant pathology laboratories (6 labs).* Lab equipment includes a Lachat auto-analyzer ($N0_3$-N, Ammonium, P) and a LECO (total C, N and S) unit, a new HPLC unit, gas chromatographs, a new IC, conventional and fluorescent ELISA, real time PCR, electrophoresis, spectrophotometers, numerous microscopes including a precision confocal laser scope and related general lab equipment. The soils and water chemistry labs are equipped to measure major macro and micronutrients in plants and soil samples as well as pressure plates for desorption curve development. There are numerous computer controlled growth chambers, incubators, chemical hoods, laminar flow hoods/biosafety cabinets and a full molecular biology laboratory. Support research buildings include a *plant and soil processing, grinding and drying facility*, an EPA-approved constant temperature *chemical storage building*, a m*echanics shop* with lathe, drill press and welding equipment, *equipment storage building*, 2 walk in freezers, a *sample storage area* for archived soil and plant samples, and a *vehicle garage*. There are GIS facilities (with considerable on-site expertise) and computer processing and storage equipment more than sufficient to deal with voluminous data. The ASRU has a fleet of 7 various sized tractors, a small backhoe, small skid-steer fork lift, one large combine, one small plot combine with yield monotor, 2 no-till planters, strip tiller, cultivators, rippers, sugarbeet harvester with yield monitor, and other miscellaneous tillage, planting and harvesting equipment. There are a total of 18 vehicles available for ASRU use ranging from vans, SUVs, pickups and larger 1 ton and 2 ton trucks. One one-ton truck has a mounted Giddings soil probe and several trailers are available to transport larger equipment. All scientists and technicians have at least Pentium IV computers.

It should be mentioned that the three scientists at the Montana State University Eastern Agriculture Research Center are co-located with offices and a laboratory in NPARL facilities. We share analytical as well as farming equipment. Dr. Jerry Bergman is the Superintendent of the MSU EARC, and also serves as Director of the NDSU Williston Agriculture Research Center (including the Nesson Valley site) with six scientists and extension specialists which greatly facilitates cooperation and collaboration with scientists at both locations with the ASRU programs

MILESTONES AND EXPECTED OUTCOMES

Milestone 1 (18 months) - In general for all studies, after year one, preliminary data will be compiled and presented at field days, at regional producer meetings, extension commodity meetings, NRCS training, etc. Start projects on: 1) the development of biologically-based, sustainable weed and disease management strategies; 2) the development of soil and residue management practices for irrigated and dryland production that improve soil water retention and minimize the use and negative impacts of agrochemicals, and 3) the development of low-cost and fast tests for quantifying soil-aggregating microorganisms, enzymes, polysaccharides and OM decomposition rates (part of the ARS National Soil Management Assessment Framework). Potential management impacts and strategies are discussed with the NPARL Focus Group and others at those early dates. There will be extension outreach through participation in grower-directed, technology transfer activities (field days, grower meetings with our university collaborators and other agencies.

Milestone 2 (19-34 months) – Start initial development of sensor-based irrigation scheduling methods for enhanced management of self-propelled water application systems; Data from experiments (at least one major project per scientist) will be presented at the ASA-CSA-SSSA, ASAE, Plant Pathology, Weed Science, Microbiology and other national and international professional meetings each year. And a minimum of one refereed journal manuscript will be submitted per scientist per year based on their research efforts. Scientists will also be encouraged to contribute to a least one popular press (e.g., Fact Sheets, regional farm magazines) and one proceedings publication each year. Participation in MSU and NDSU extension meetings and field days will be strongly encouraged.

Milestone 3 (35-48 months)- After 4 years, we will have identified some of the best rotations with respect to soil quality and economic productivity. We will have quantified water use requirements and N requirements of sugarbeets, barley and potatoes, and fine-tuned our quantitative understanding of the water use and N requirements of various center pivot irrigated and dryland crops. We expect to identify the most productive soil environments in relation to crop production, as well as, in relation to overall biological activity and improved soil quality. Long-term crop rotation efforts will continue because our two and three year rotations will have only completed 2 cycles or less after 4 years and the steady state for C and N turnover may not have been stabilized. Fact sheets will be developed, passed out at grower meetings and placed on our website on: 1) biologically-based, sustainable weed and disease management strategies; 2) soil and residue management practices for irrigated and dryland production that improve soil water retention and minimize the use and negative impacts of agrochemicals; 3) low-cost and fast tests for quantifying soil-aggregating microorganisms, enzymes, polysaccharides and OM decomposition rates; 4) sensor-based irrigation scheduling methods for enhanced management of self-propelled water application systems; and, 5) improved tillage management techniques and alternative crop rotations that optimize soil health, soil biological diversity, biologically-based cropland weed control, residue management, water quality and net returns (technology transfer). Manuscripts describing the initial results will be in the publishing stages. Collaborative simulation model testing/validation will be a major component effort after the first three years. The ability to test developed paradigms at this point using predictive models will help validate the state of our knowledge and focus local and regional research efforts. Outreach will be through participation in grower-directed, technology transfer activities and by presentations at the ASA-CSA-SSSA, ASAE, Plant Pathology, Weed Science, Microbiology and other national and international professional meetings.

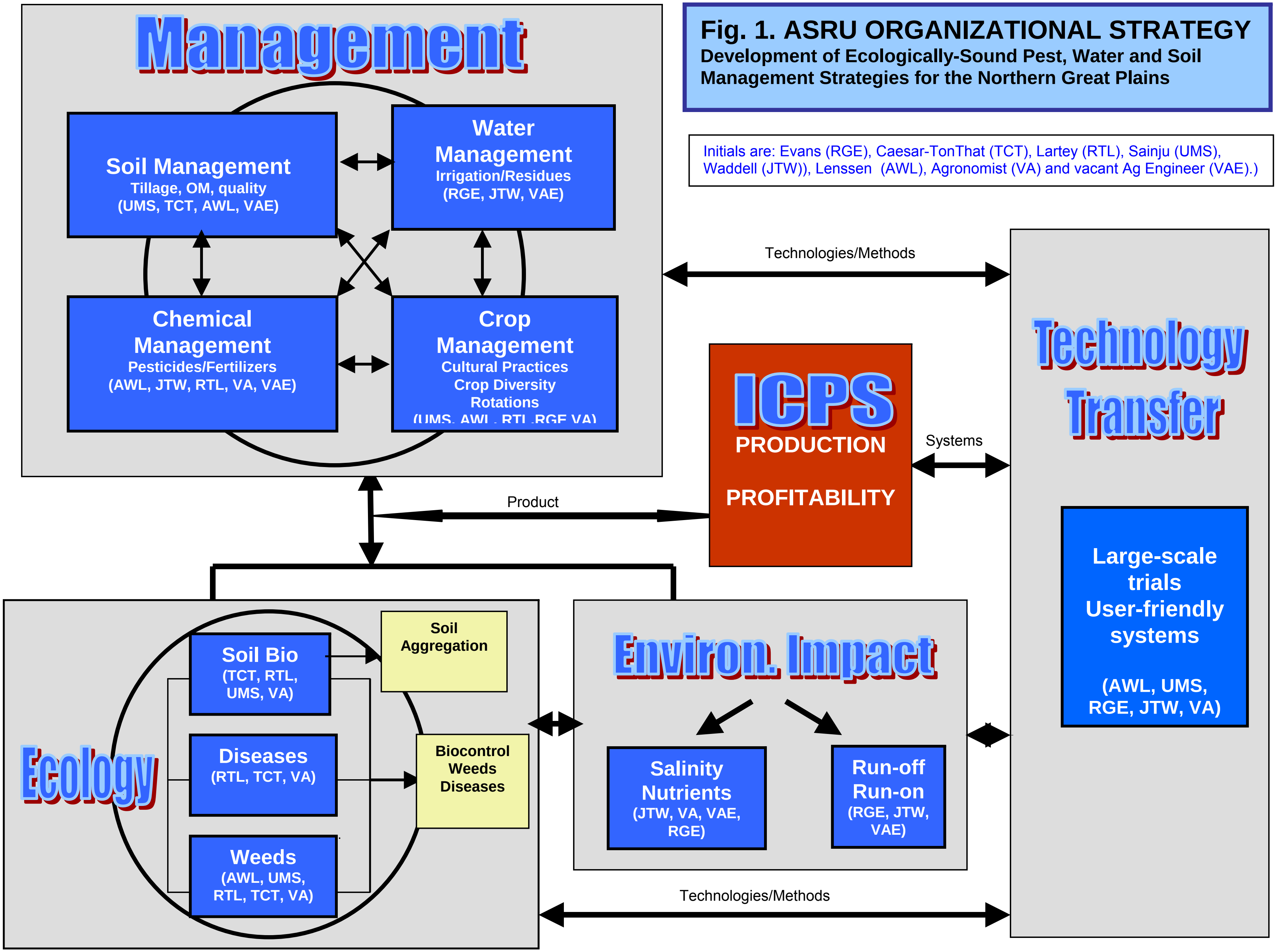
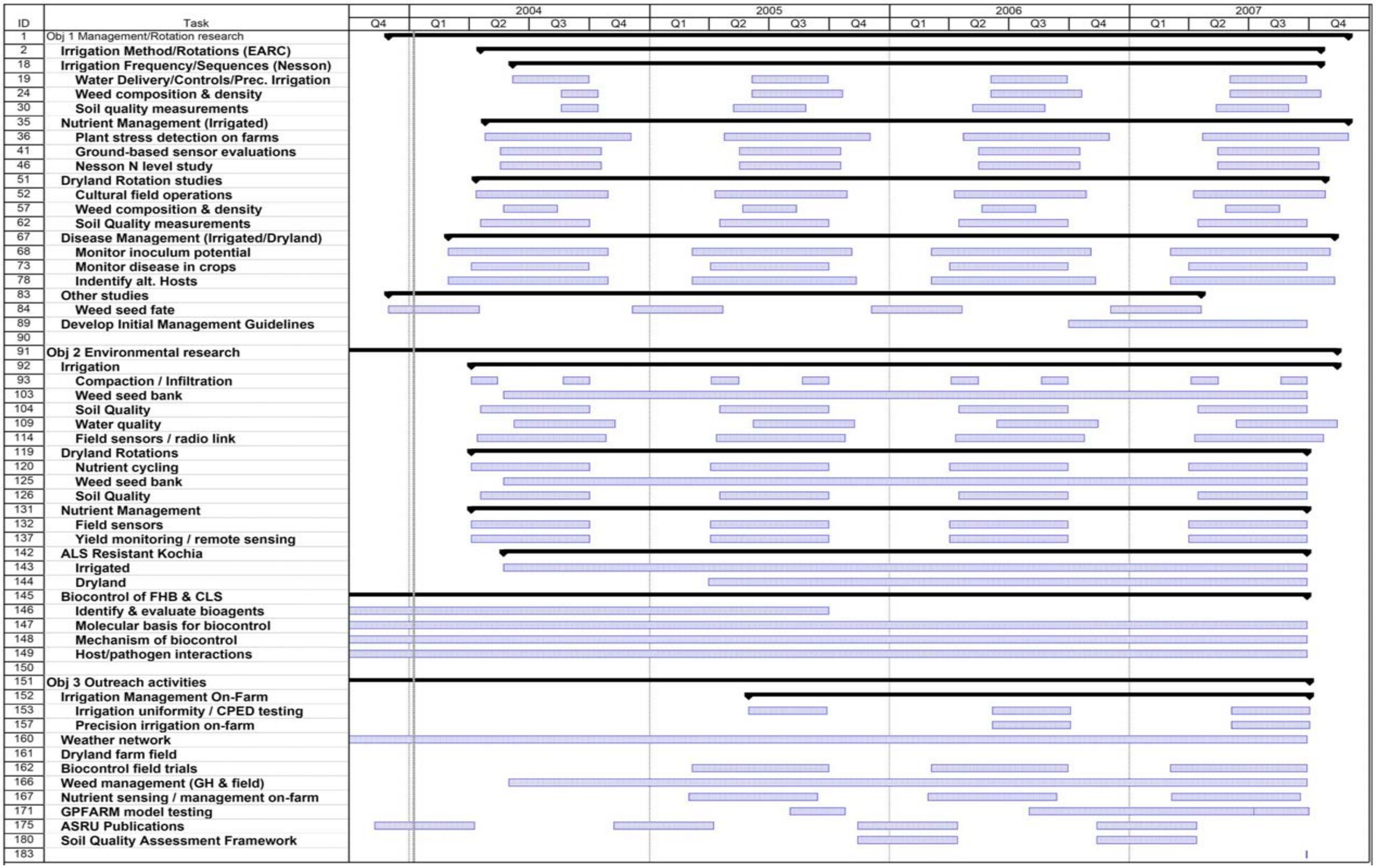


Fig. 1. ASRU ORGANIZATIONAL STRATEGY
Development of Ecologically-Sound Pest, Water and Soil Management Strategies for the Northern Great Plains

Figure 2. Gantt chart showing milestones and timelines for the CRIS project: Ecologically- Sound Pest, Water and Soil Management Strategies for Northern Great Plains Cropping Systems.



APPENDIX A: MAPS AND PLOT PLANS

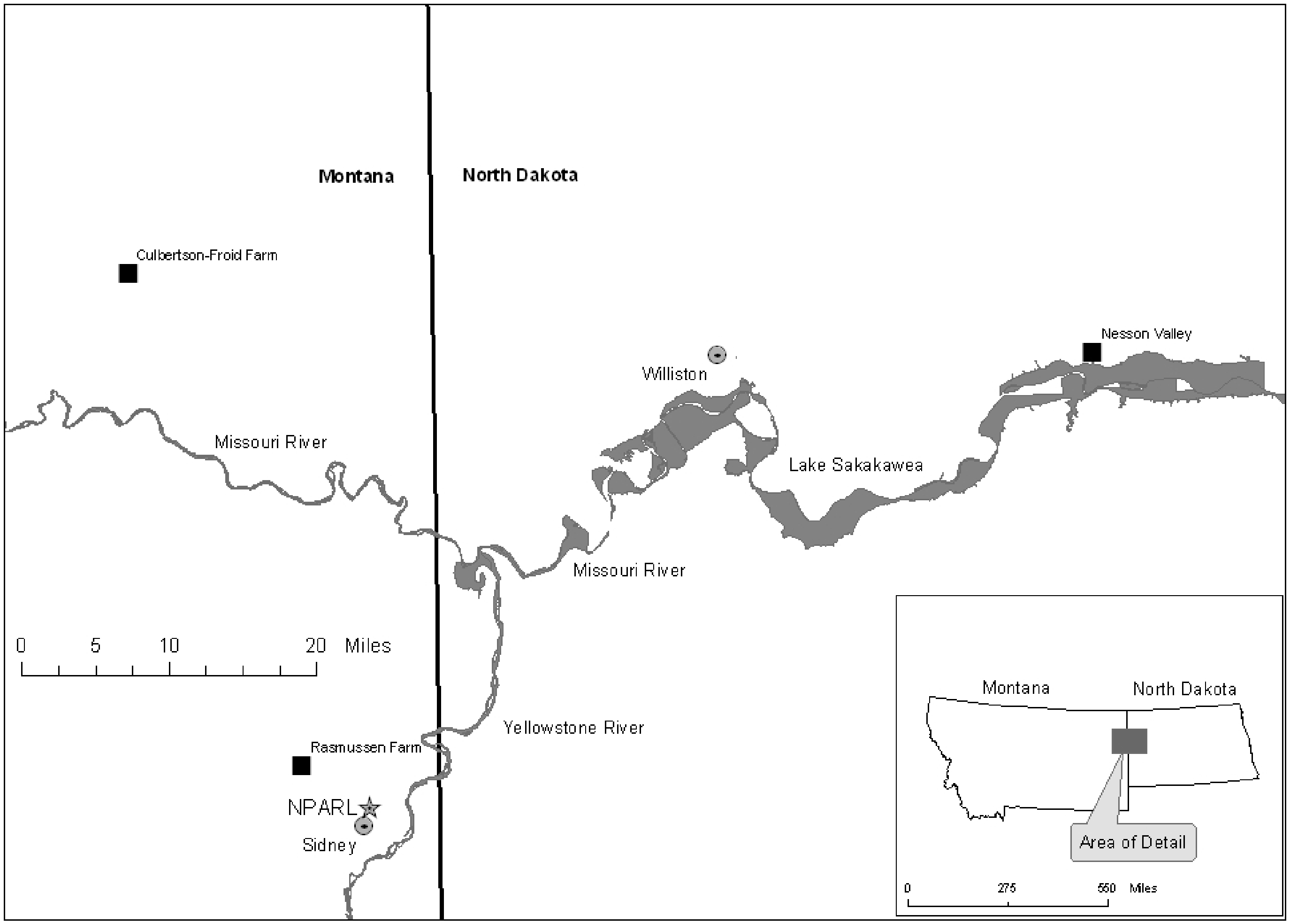


Figure A-1. Map showing general locations of research plots (black boxes) relative to the NPARL in Sidney, MT. The Rasmussen Farm is about 10 km, Culbertson-Froid is about 50 km and the Nesson Valley is about 120 km one way. We are also working at the MSU EARC farm adjacent to NPARL site. There are (or will be) also several grower cooperators located in this large region.
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PRIMARY DRYLAND RESEARCH PLOTS

Table 1. Proposed cropping sequences in the dryland rotation and management study at the Culbertson-Froid and Rasmussen sites. Note that the Culbertson-Froid set of experiments will start in 2005.

Crop Diversity-Crop Management Experiment, Culbertson-Froid and Rasmussen

Rotation type	2004	2005	2006	2007	2008
One-year	S Wheat	S Wheat	S Wheat	S Wheat	S Wheat
Two-year	S Wheat	Field pea	S Wheat	Field pea	S Wheat
	Field pea	S Wheat	Field pea	S Wheat	Field pea
Three-year	S Wheat	Barley (hay)	Field pea	S Wheat	Barley (hay)
	Barley (hay)	Field pea	S Wheat	Barley (hay)	Field pea
	Field pea	S Wheat	Barley (hay)	Field pea	S Wheat
Four-year	S Wheat	Barley (hay)	Corn	Field pea	S Wheat
	Barley (hay)	Corn	Field pea	S Wheat	Barley (hay)
	Corn	Field pea	S Wheat	Barley (hay)	Corn
	Field pea	S Wheat	Barley (hay)	Corn	Field pea

Table 2. Dryland management treatments and practices for the primary integrated crop production systems being used in the basic investigations.

Crop management treatments		Management Practice			
Crop	Management type	Final plant stand/ac	Fertilizer Placement	Planting date	Row spacing
Spring wheat	Conventional	900,000	Broadcast	Conventional	8 in.
	Ecological	1,250,000	Banded	Delayed	8 in.
Barley	Conventional	900,000	Broadcast	Conventional	8 in.
	Ecological	1,250,000	Banded	Conventional	8 in.
Corn	Conventional	18,000	Broadcast	Conventional	32 in.
	Ecological	24,000	Banded	Conventional	24 in.
Pea	Conventional	275,000	Broadcast w inoculant	Conventional	8 in.
	Ecological	350,000	Starter fert. w/inoculant	Conventional	8 in.

All dryland rotations are produced under both conventional- and zero tillage and conventional and ecological crop management systems. All components of each rotation are present every year within each of three replicates, resulting in 120 plots at each research site. The rotations represent a range of diversity, from continuous spring wheat to a four-year rotation with four different crops. Conventional management practices are representative of those used by growers in the MonDak region for plant stands, fertilizer placement, seeding dates, and row spacing. The ecological management practices are used to increase crop competitiveness and decrease weed interference by using combinations of increased crop stand densities, decreased row spacing, banded fertilizer application, and delayed seeding to allow preplant chemical “burndown” (e.g., Roundup® herbicide) or tillage of the initial weed flush prior to planting. Conventional tillage includes shallow chisel plows or disking followed by wide sweeps with a rod to firm the seedbed before planting.

We will also vary the height of wheat stubble left in the field to catch snow to improve spring soil water conditions. The ecological treatments will leave higher stubble (e.g., 20-30 cm) with all the straw left in the field, whereas the conventional will leave short stubble (6-8 cm) with the straw baled and removed (a common grower practice to increase short-term net economic returns.)

Starting in 2005 (same time we will be starting the new crop rotation study), we would like to start a set 4 of continuous “flex-cropping” plots at the Culbertson-Froid site using crops and management practices (e.g., varieties, herbicides, possible markets) suggested each year by the boards of the Roosevelt and Sheridan County Conservation Districts (co-owners of the site). We will monitor various plant and soil parameters and collect yields and compare the economic returns with our research projects. It is hoped that this will provide more of a focus for heightened grower interest in our overall dryland research program since it would be part of our annual field day at the site.

PRIMARY IRRIGATION RESEARCH PLOTS

Table 3. Proposed primary cropping rotations in the irrigated integrated crop production systems to be used in the MSU-EARC linear move irrigation investigations at Sidney starting Fall 2003.

Crop Sequence, East EARC Plots
Irrigation Treatments: MESA, LEPA

Rotation	2003	2004	2005	2006	2007	2008	2009
1	Barley	Sbeet-C	Barley	Sbeet-C	Barley	Sbeet-C	Barley
2	Barley	Sbeet-ST	Barley	Sbeet-ST	Barley	Sbeet-ST	Barley
3	Barley	Barley	Sbeet-C	Barley	Sbeet-C	Barley	Sbeet-C
4	Barley	Barley	Sbeet-ST	Barley	Sbeet-ST	Barley	Sbeet-ST

4 replications: two irrigation method treatments, Stipped-Block crossover statistical design that changes year to year (56 plots—see below). ST is strip tillage. C is conventional Tillage. MESA refers to mid-elevation sprinkler applications; LEPA refers to low energy precision application, which applies water directly on the soil in every row (bubblers) in order to apply comparable water amounts to MESA heads.

Irrigated conventional tillage (CT) and strip till (ST) are the primary tillage treatments for all sugarbeet rotations. CT starts in the fall will consist of two tillage passes with a combination mulcher-ripper equipped with shatter blocks and shatter wings on shanks at a 61 cm spacing, followed by two passes with a roller harrow and two passes with a land plane (typical grower practice). Prior to planting in the spring, an S-tine tillage tool will be used to kill small weeds and create a seedbed suitable for conventional planting equipment. CT barley is tilled with an S-tine tool or disk in the spring after sugarbeets. The ST sugarbeet treatments utilize a custom built coulter and shank tiller (about a 40 cm wide strip) with two fertilizer boxes as the primary tillage for sugarbeets in the fall. ST barley is tilled in the spring to mitigate the effects of sugarbeet harvesting activities prior to planting. A conventional grain drill is used for planting the barley.
The following 5 figures (A-2 through A-6) are presented as examples to show the individual treatments by year for the EARC set of experiments. The Nesson Valley research plots will have a

similar design except varied by frequency rather than irrigation method.

Cropping sequences in the irrigated integrated crop production systems to be used in the linear move irrigation investigations at the NDSU Nesson Valley site starting Spring 2005 (some field work will be Fall 2004.)

Crop Sequence, Nesson Valley

Irrigation Treatments, MESA-Frequency 1, MESA-Frequency 2

Rotation	2003	2004	2005	2006	2007	2008	2009	2010
R1 S1	Grass	Grass	Sbeet-C	Potatoes	Barley	Sbeet-ST	Potatoes	Barley
R1 S2	Grass	Grass	Barley	Sbeet-ST	Potatoes	Barley	Sbeet-ST	Potatoes
R1 S3	Grass	Grass	Potatoes	Barley	Sbeet-ST	Potatoes	Barley	Sbeet-ST
R2 S1	Grass	Grass	Potatoes	Sbeet-C	Barley	Potatoes	Sbeet-C	Barley
R2 S2	Grass	Grass	Barley	Potatoes	Sbeet-C	Barley	Potatoes	Sbeet-C
R2 S3	Grass	Grass	Sbeet-C	Barley	Potatoes	Sbeet-C	Barley	Potatoes

Six rotations: two irrigation frequencies (15 and 30 mm of water use), 4 replications (48 plots). ST is strip tillage. C is conventional Tillage. (Potatoes may also be strip-tilled.) MESA refers to mid-elevation sprinkler applications. Minimum tillage techniques will be used whenever possible throughout this experiment.. Stripped block statistical design. In effect, all parts of each sequence are present every year.

APPENDIX B: ADDRESSING NP207 CRITERIA

There are at least ten characteristics distinguish the NP207 National Program from other national programs, so it is therefore designed differently. Distinguishing features include increased emphasis on stakeholder participation and on-farm research approaches. Projects addressing the entire spectrum of agricultural approaches and management strategies and philosophies are included in this national program. Information transfer will be facilitated through interactions and by assembling large databases that include background and management information as well as data from experiments conducted at scales much greater than traditional projects. Specific project attributes of the NP207 program that are addressed by this proposal are:

1. *A complete initial assessment of the current situation to understand the system. This understanding is needed to identify problem(s) as opposed to problem symptoms and to identify gap(s) in knowledge and/or information delivery*.

   This research program is emphasizing minimum tillage/conservation tillage practices whenever possible. Many of these practices have been around for lots of years and their benefits are well known by growers, but the have had low rates of adoption due to various economic and cultural barriers. Our guiding philosophy in the development of this project has been the "removal of barriers" to the adoption of these improved practices in both dryland and irrigated production systems. For example, a major constraint to dryland minimum tillage and intensive every year cropping has been effective, low cost weed control on crops with low rates of return. We are addressing these concerns through an ecological approach that examines ways to manipulate the plant-soil ecosystem to keep various weed species below economic thresholds. The same is true with disease control. For center pivot irrigated systems, another major barrier is probably sustainability in terms of economics (including rising electric power costs) and minimizing environmental impacts. We are focusing on understanding the problem at a basic level and developing the applications that work.

2. *Active participation by producers and stakeholders in 'on-farm' and/or 'controlled' studies.*

   This project has received a large amount of input from producers and other stakeholders through our Focus Group, an external peer review of our programs and a detailed strategic planning process during the last two years. Our customers and stakeholders have bought into the vision of this program and have gone to Congress for the needed personnel (as evidenced by the large number of "new" members.)

3. *Interdisciplinary teams and multi-organizational collaborators.*

   Most of the low hanging fruit in agricultural research has already been picked. The problems are becoming ever more complex due to environmental and regulatory as well as economic concerns. There is a major shift towards quality and safety of our production systems that is being driven by the consumer. Consequently, many the remaining problems facing production agriculture in the USA can only be addressed by dedicated multidisciplinary research teams. We have wide range of expertise at the locations and with our broad range of local, national and international collaborators, and the team members are dedicated to solving these problems. The list of collaborators and supporting letters showing their willingness to participate is ample evidence of this structure.

4. *The science of interactions among components as well as with the entire 'system' and the 'environments' in which they operate.*

   Defining the crucial components of these production systems and the science behind their interactions is fundamental to this research. This project is considering the plant community ecosystem (crops, weeds, etc), soils and climate and their interactions related to crop production, soil quality, soil water and nutrient fluxes, crop water use and nutrient uptake and yield. The research is intended to integrate eco-physiological processes with simulation modeling and data management, and help define the environmental implications of these crop production strategies. Our weed and cropping systems work seeks to characterize the ecological traits of weed species growth and population dynamics to develop guidelines for crop sequencing within integrated weed management systems; and to integrate crop, weed, and foliar disease management principles to develop cropping systems for sustainable agricultural production. Soil productivity is being defined in terms of physical, chemical and biological properties, their variations, changes in availability of macro and micro plant nutrients; soil fertility evaluation and indicators; organic and inorganic fertilizers; fertilizer application and management; systematic review of crop production.

5. *Optimum use of long-term studies to provide information for short-term answers while striving to quantify the long-term impacts associated with various options or system scenarios.*

   The primary studies (2 dryland and 2 irrigated) defined in this proposal are long-term projects by intent. We must have the long term combined effects of these systems to determine "steady state" fluxes and conditions. In addition, experience has shown us many times that even though we have solved one problem another always takes its place (Nature always bats last). There is also a long-term dryland crop rotation study at the Culbertson-Froid site that was started in 1982 and is a great resource.

6. *The infrastructure to address problems of regional and/or national scope when appropriate, which may require developing projects across ARS locations.*

   We are developing multi-location projects with other university and ARS laboratories where each is conducting the same experiment or closely related experiments. Generally, these address small parts of the total puzzle. Examples include some of the sensor work and various aspects of the soil quality program.

7. *A fully documented database management plan and quality assurance/quality control protocol.*

   We are in the process of setting up a coordinate ACCESS database for the storage of the resulting project data collection activities so that it is available (at least to read) by all members of the team located in Sidney only (due to cyber security issues). These data include GPS coordinates of data collection activities, GIS maps, EXCEL spreadsheets, and SAS statistical output sheets as well as common, current data collection protocols and procedures for various procedures. Our intent is to also include manuscript drafts within this umbrella. It will be a major effort to keep this database updated and valuable to the team members. Our weekly meetings will be invaluable in this regard.

8. *Maximum use of natural ecological and biological resources where appropriate, considering diverse production options.*

   Our objectives are the development of cropping systems that naturally limit the elevation of an organism to pest status and the development of farming practices that are compatible with ecological systems. This NP207 Program is centered on diversified cropping rotations that include cereals, legumes, annual forages, oilseed crops and horticultural crops. These rotations can carry considerably more economic risk to the grower due to poorly developed markets and drought as well as resistance from lenders for adoption of these "untried" or novel ideas. The options for diversified crops are also limited because choices must fit within the current Farm Programs, crop insurance guidelines, existing and future markets as well as equipment availability and costs associate with the new ventures. However, our projects on manipulating cultural management practices and weed/disease biocontrol make maximum use of natural ecological and biological resources.

9. *The appropriate scale for the research objectives and goals of all partners, stakeholders, and cooperators involved in planning, conducting, and interpreting the data.*

   This research is being conducted on at least two scales: the detailed plot level and at the field level. Conducting research across multiple levels is necessary to determine problems that become evident when "scaling up" at practice that were not a factor in the plot research. A regional scale is added through our collaboration with decision support software (e.g., GPFARM), GIS and remote sensing efforts.

10. *Economic and environmental risk and social impact assessments.*

    We do not currently have an environmental and social risk impact assessment component in place. However, as this research evolves and matures, it is our full intention to do so. Benefits potentially derived from this research include reduced chemical usage, improved efficiency, better cultural control options for pest management, and the development of integrated production systems based upon a better understanding of agroecological principles.

In addition to specific project attributes, several mechanisms will differentiate the NP207 National Program from other national programs. These will include mechanisms to:

1. *Incorporate information from other national programs and diverse sources and fields such as economics, marketing, and sociology.*

   As can be seen in the write up, this NP207 project directly contributes to the NP201, 202, 303 and 304 programs even though it is only coded for NP 207 and NP201. As a result there is considerable interaction between Sidney and participants in these national programs. We are definitely considering local, national and international market opportunities and the National Farm Program in selecting the crops used this experiment. We rely on input from our Focus Group as well as growers and various lending agency personnel in making these decisions.

2. *Exchange information with and disseminate research information to clients, partners, stakeholders, and those who are doing basic research.*

   Various members of the team actively participate in informal national groups such as the National Soil Assessment Framework effort, precision agriculture and irrigation forums. We also have a strong commitment to publish as well as disseminate information directly to the end users through grower field days, commodity group meetings, popular press, etc.

3. *Conduct periodic evaluations with all partners, cooperators, and stakeholders to ensure relevant progress in addressing their needs and requirements.*

   Results are discussed with our Focus Group at least twice a year and their input solicited as to relevance and impact. Their comments are carefully considered as we put together plans for the upcoming cropping seasons or to plan new side experiments to test various new hypotheses.

4. *Foster a national focus by encouraging more frequent interaction among scientists contributing to this program to prompt sharing of new technologies, insights, and techniques for analysis.*

   All scientists attend at least one national or international scientific meeting in their relevant disciplines and expertise each year. In addition, most scientists participate in specific research related programs such as regional projects and various technical committees in their professional societies. These activities as well as subscriptions to relevant scientific journals serve to keep them abreast of current developments and emerging technologies. The assistance of the National Agricultural Library in Beltsville, MD is invaluable in providing copies of literature and their assistance in searches, particularly in light of the geographic isolation in Sidney relative to suitable university library facilities (about 450 miles east, west or south).

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